



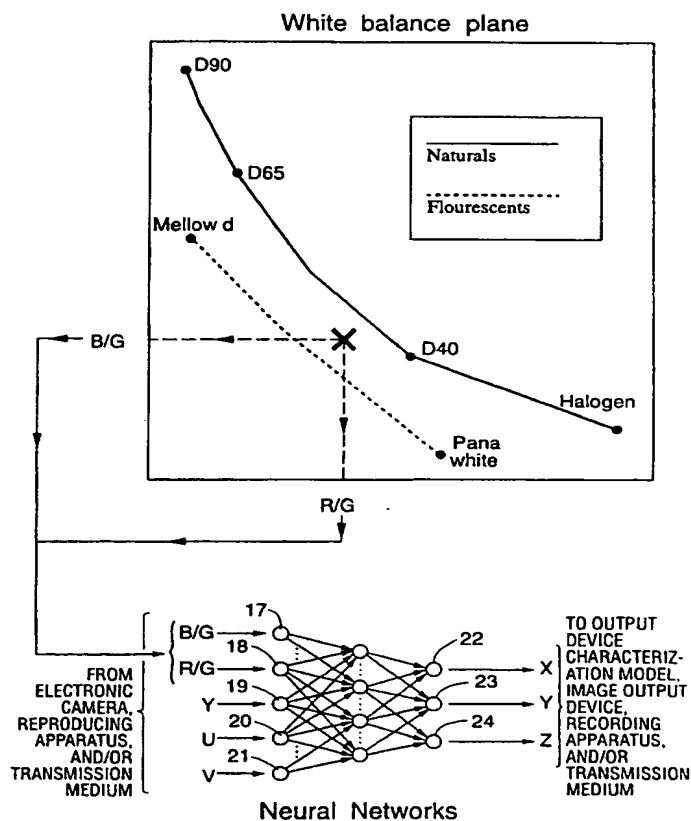
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(54) Title: METHODS AND APPARATUS FOR COLOR DEVICE CHARACTERIZATION

(57) Abstract

Methods and apparatus for color correction of color image data obtained by an electronic camera determine a correction to data representative of the color image based upon an estimated illuminant using a neural network, multilayer perceptron models and/or coactive neuro-fuzzy inference system models, and apply the correction to the data representative of the color image. Data representative of the color corrected data may be recorded or transmitted. A method of recording image data obtained by an electronic camera captures a color image, generates data representative of the image, estimates an illuminant for the captured color image, generates data representative of the estimated illuminant and records the data representative of the image with the data representative of the estimated illuminant. A method of transmitting image data obtained by an electronic camera captures a color image, generates data representative of the image, estimates an illuminant for the captured color image, generates data representative of the estimated illuminant and transmits the data representative of the image with the data representative of the estimated illuminant.



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METHODS AND APPARATUS FOR COLOR DEVICE CHARACTERIZATION

5 Background of the Invention

1. Field of the Invention

The present invention relates to color correction of images, and in particular relates to methods and apparatus for color device characterization, correcting color of a color image obtained by an electronic camera, transmission of color corrected data and a recording medium having recorded thereon a color corrected data of a color image.

2. Description of the Related Art

There are known in the art two approaches for performing color correction for an image captured by an electronic color camera. A first approach is to directly convert the camera's output data into the same color space as camera's output color space with improved color accuracy. For instance, when the camera's output space is YUV (defined below), the color correction model's input and output spaces are YUV, but with higher color accuracy at the output YUV. Hereinafter, this approach will be referred to as "device specific color correction." "YUV" is a color representation which is typically used in connection with video transmission. "Y" represents luminance, "U" represents a component of colors corresponding approximately to blue minus yellow, while "V" represents component of colors corresponding approximately to red minus cyan. Other color representations include "RGB" (red, green blue) and "YCC" where YCC indicates any color space consisting of one luminance factor and two chrominance factors. The above-described YUV is one example of a YCC color representation. YIQ,

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is another example of a YCC color representation, where "I" is a component of colors corresponding approximately to yellow-ish red minus light blue, while "Q" is a component of colors corresponding approximately to violet minus green-ish yellow. YCbCr (luminance, chrominance-blue, chrominance-red is yet another example of a YCC color representation.

A second approach for color correction is divided into two steps. First, the camera's output color space is once converted into a colorimetric space (XYZ or $L^*a^*b^*$), the space which is specified by CIE (International Illumination Committee, originally published in the French language). A colorimetric color space attempts to describe color of natural objects perceived by human eyes. Color data described in a colorimetric space corresponds to the original color of the images taken by an electronic color camera. In a second step, the color data converted into such a colorimetric space is then converted into an output device's (computer monitor or printer) specific color space, where the entire image path can provide colorimetrically correct color reproduction. This two-step concept is incorporated in the ICC (International Color Committee) color profile format, which is commonly used in computer image processing where relatively high accuracy is required in color reproduction. In the context of the color correction based on ICC's concept, the intermediate colorimetric space is often referred to as a "device independent color space." Therefore, this color correction approach is referred to as "device independent color correction."

To perform the above-described device-independent color correction, one should attempt to determine an inverse function of a camera's color transformation. This step is called "color device characterization" for an electronic camera, and such characterization is employed to correct color of images obtained by the electronic camera. The conventional practice for determining the inverse

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function of an electronic camera's color transformation is to apply a method widely used for determining an inverse function of image scanners' color transformation. This approach has been considered reasonable, because most color cameras have signal processing similar to that of image scanners.

Figure 1 shows the signal-processing diagram that is used in both image scanners and most electronic color cameras. In Figure 1, input data of image sensor 104 of camera 100 is assumed to be in colorimetric space XYZ, which is provided to inputs 101, 102 and 103, respectively. The output space of image sensor 104 is RGB, while the camera's output space is YCC. Camera output is provided at outputs 110, 111, and 112, corresponding to Y, C and C, respectively.

A simple reverse-model, shown in Figure 2, can be used to approximate the inverse function of the color transformation formed by the image sensor camera 100 shown in Figure 1. In Figure 2, each block should perform inverse conversion of corresponding blocks in Figure 1. The pairs of corresponding blocks are 104-124, 151-161, 152-162, 153-163 and 109-122. Specifically, matrices 104 and 109 should be inverse matrices of 124 and 122 respectively. Tone reproduction curves ("TRCs"), which are usually implemented by one-dimensional lookup tables ("1D-LUTs") 151, 152, and 153, should be inverse functions of 1D-LUTs 161, 162 and 163, respectively. Since this color correction model consists of matrices and TRCs, it is called a "TRC-matrix model."

As shown in Figures 1 and 2, the color transformation of image sensor 104 is linearly approximated by a 3x3 matrix 124. According to color science for electronic cameras, an image sensor's spectral analysis characteristics ideally should be a linear combinations of color matching functions xyz specified by CIE, that is, a set of spectral functions which represent human eye's color

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sensitivity. Since all color cameras are designed to target these ideal characteristics, in many cases a 3x3 matrix can well approximate an image sensor used in electronic cameras, thereby providing a reasonably accurate inverse function of the camera's color transformation. This TRC-matrix model approach, however, cannot perform an accurate color correction under some circumstances.

Approximation accuracy

When an image sensor's color transformation cannot be well approximated by a 3x3 matrix in the TRC-matrix model (124 in Figure 2), color correction cannot be accurate. This situation can likely occur in many entry-level electronic cameras. This is also the case when the camera's signal processing does not match the configuration shown in Figure 1, such that the configuration of Figure 2 can no longer be a reverse model of the camera. For instance, Figure 3 is a block diagram which illustrates signal processing typically used in a CMYG (Cyan, Magenta, Yellow, and Green, also referred to as "complementary color") electronic color camera. At first glance, Figure 2 cannot work as a reverse model for the signal processing of Figure 3. In addition, it is not easy to construct a simple reverse model for the signal processing performed by the system of Figure 3, due to structural complexity of a CMYG camera's signal processing.

Illuminant dependency

In the case of an electronic camera, whether it be a still camera or one intended to record a succession of still or moving images, there is a somewhat unique problem, more specifically, that of illuminant dependency of color transformation. While an image scanner captures images using one fixed built-in illuminant all the time, an electronic camera captures images under a variety of

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illuminants, for example, outdoors at dawn, mid-day or late afternoon, indoors with fluorescent, incandescent or other types of artificial lighting, a combination of artificial lighting, or even a combination of natural (outdoor) and artificial lighting. In an electronic camera, there is a mechanism to estimate the illuminant at the time of image capturing, wherein the camera's gain settings at R, G, and B channels are adjusted according to the on-camera illuminant estimation, so that the final output image has $R = G = B$ with respect to a white object. This operation is called "white balancing," and the gain adjustment is placed between image sensor 104 and 1D-LUTs 105 in Figure 1, although it is not shown in the diagram. Usually, color transformation of a camera changes depending on the setting of white balancing. In other words, an electronic camera has illuminant dependency in its color transformation. It means color distortion or error caused by an electronic camera changes depending on illuminant. Therefore, for highly accurate color correction, it is necessary to prepare for inverse functions of the camera's color transformation under all possible illuminants, which is impractical. One existing solution for this problem is to prepare for a set of inverse functions (likely in a form of ICC color profile, using either a TRC-matrix model or a three-dimensional lookup table) of color transformation under several representative illuminants. A user then has to manually select from the set of preset inverse functions, considering which inverse function is the best fit to the illumination under which the user actually captured the image. This not only is a burden for the user, but also can result in inaccurate color correction if the user's selection is inappropriate. Furthermore, inaccurate correction can also occur when the actual illumination used for the image capture falls between the preset inverse functions. This is a limitation of the lookup-table based (TRC-matrix) method. Another limitation of

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the look-up table based method is its inability to accurately correct color under multi-illuminant conditions. An alternative to the TRC-matrix method is the three dimensional lookup table ("3D-LUT"). Although such a 3D-LUT is more accurate than the TRC-matrix, the size of the correction model is huge, and it is, as with the TRC-matrix method, incapable of accurately correcting color under multi-illuminant conditions. Thus, it would be desirable to provide a method and apparatus for accurately correcting the color of images taken by an electronic camera under arbitrary illuminants.

Summary of the Invention

It is an object of the invention to provide a method and apparatus for correcting the color of images obtained by an electronic camera under a variety of illuminants.

It is also an object of the invention to provide a method and apparatus for characterizing a color device.

It is an additional object of the invention to provide a method and apparatus for correcting the color of images obtained by an electronic camera under a combination of illuminants.

It is yet another object of the invention to provide a recording medium having recorded thereon data representative of color corrected color images.

It is yet an additional object of the invention to provide a method of transmitting data representative of color corrected color images.

It is a feature of the invention to correct color of a color image by utilizing a neural network as a function approximator to overcome the limitations of the look-up table method in determining a correction to data representative of the color image.

It is a feature of the invention to correct color of a color image by utilizing a multilayer perceptron ("MLP"), a form of neural

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network, to determine a correction to data representative of the color image.

5 It is yet another feature of the invention to correct color of a color image by utilizing a coactive neuro-fuzzy inference system ("CANFIS") model to determine a correction to data representative of the color image.

It is yet a further feature of the invention to perform an automatic color correction of a color image obtained by an electronic camera in the case of multi-illuminant conditions.

10 It is yet another feature of the invention to convert image data into XYZ space, thereby providing better accuracy in white point and in color under sophisticated off-camera illumination estimation.

It is yet an additional feature of the invention to easily realize color constancy by modifying or replacing a training data set.

15 It is an advantage of the invention to a higher color correction accuracy of images obtained by an electronic camera than is generally possible with a conventional TRC-matrix.

20 It is a further advantage of the invention to allow electronic camera users to concentrate on composition instead of spending time on color correction during a photo shoot, but also at the time of displaying and/or printing a photo.

25 According to one aspect of the invention, there is provided a method of correcting color of a color image obtained by an electronic camera, comprising the steps of determining, using a neural network, a correction to data representative of the color image based upon an estimated illuminant of the color image; and applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

30 According to another aspect of the invention, there is provided a method of correcting color of a color image obtained by an electronic camera, comprising the steps of determining, using a

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5 multilayer perceptron model, a correction to data representative of the color image based upon an estimated illuminant of the color image; and applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

10 According to a further aspect of the invention, there is provided a method of correcting color of a color image obtained by an electronic camera, comprising the steps of determining, using a coactive neuro-fuzzy inference system model, a correction to data representative of the color image based upon an estimated illuminant of the color image; and applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

15 According to yet another aspect of the invention, there is provided an apparatus for correcting color of a color image obtained by an electronic camera, comprising a neural network for determining a correction to data representative of the color image based upon an estimated illuminant of the color image and for applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

20 According to yet a further aspect of the invention, there is provided an apparatus for correcting color of a color image obtained by an electronic camera, comprising a multilayer perceptron model for determining a correction to data representative of the color image based upon an estimated illuminant of the color image, and for applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

25 According to another aspect of the invention, there is provided an apparatus for correcting color of a color image obtained by an electronic camera, comprising: a coactive neuro-fuzzy inference system model for determining a correction to data

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representative of the color image based upon an estimated illuminant of the color image, and for applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

5 According to a further aspect of the invention, there is provided a recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of determining, using a neural network, a correction to data representative of the
10 color image based upon an estimated illuminant of the color image; applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and recording on the recording medium data representative of the corrected data.

15 According to yet another aspect of the invention, there is provided a recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of determining, using a multilayer perceptron model, a correction to data
20 representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and recording on the recording medium data representative of the corrected data.

25 According to yet another aspect of the present invention, there is provided a recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of determining, using a coactive neuro-fuzzy inference system model, a correction to
30 data representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data

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representative of the color image, wherein the illuminant comprises multiple sources of illumination; and recording on the recording medium data representative of the corrected data.

5 According to an aspect of the invention, there is provided a method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of determining, using a neural network, a correction to data representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data representative
10 of the color image, wherein the illuminant comprises multiple sources of illumination; and transmitting data representative of the corrected data.

 According to another aspect of the invention, there is provided a method of transmitting color corrected data of a color
15 image obtained by an electronic camera, comprising the steps of: determining, using a multilayer perceptron model, a correction to data representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data representative of the color image, wherein the illuminant comprises
20 multiple sources of illumination; and transmitting data representative of the corrected data.

 According to a further aspect of the invention, there is provided a method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of:
25 determining, using a coactive neuro-fuzzy inference system model, a correction to data representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and transmitting data
30 representative of the corrected data.

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According to an aspect of the invention, there is provided a method of recording image data obtained by an electronic camera, comprising the steps of: capturing a color image and generating data representative of the image; estimating an illuminant for the captured color image and generating data representative of the estimated illuminant; and recording the data representative of the image with the data representative of the estimated illuminant.

According to a further aspect of the invention, there is provided a method of transmitting image data obtained by an electronic camera, comprising the steps of: capturing a color image and generating data representative of the image; estimating an illuminant for the captured color image and generating data representative of the estimated illuminant; and transmitting the data representative of the image with the data representative of the estimated illuminant.

These and other objects, features and advantages will become apparent when considered with reference to the following description and the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a block diagram of a signal processor used in both image scanners and electronic color cameras.

Figure 2 is a reverse signal processor for use in connection with the signal processor of Figure 1.

Figure 3 is a block diagram of a signal processor typically used in a complementary color electronic camera.

Figure 4A is a block diagram of an embodiment of a color correcting apparatus of the present invention in which a neural network is utilized to generate an inverse function (or mapping) of an electronic camera's color transformation.

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Figure 4B is a diagram of an embodiment of a color correcting apparatus of the present invention in which multilayer perceptrons are utilized to generate an inverse function (or mapping) of an electronic camera's color transformation.

5 Figure 5 is a diagram of an embodiment of a color correcting apparatus of the present invention in which single multilayer perceptron are utilized to generate a color corrected output space converted image.

10 Figure 6A is an illustration of a dogleg trajectory having a piecewise linear curve determined by the Cauchy step and the Newton step, connecting θ_{now} and θ_{Newton} by the route through θ_{Cauchy} .

Figure 6B is an illustration of a dogleg step which leads to θ_{next} , where the dogleg step is a piecewise linear approximation to a restricted Levenberg-Marquardt step within the trust region.

15 Figure 7 is a graph which illustrates a comparison in color difference under a D65-illuminant between a single multilayer perceptron approach and a conventional look-up-table based (TRC-matrix) approach.

20 Figure 8 is a diagram of the architecture of a CANFIS neuro-fuzzy model of the present invention.

Figure 9 is a graph which illustrates representative illuminants and related "natural" and "fluorescent" curves.

25 Figure 10 is a graph which illustrates fuzzy partitioning by four bell-shaped membership functions on a transformed white balance plane.

Figure 11 illustrates a data distribution on original coordinates of a white balance plane.

Figure 12 illustrates a data distribution on normalized coordinates of the white balance plane.

30 Figure 13 illustrates a neural network transformed distribution on transformed coordinates of the white balance plane.

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Detailed Description of the Preferred Embodiments

To solve the problems described above, a neural network (e.g., a MLP) or a CANFIS neuro-fuzzy model is utilized. Although the invention is applicable to both "device specific" and "device independent" approaches, the embodiments disclosed herein are described herein in relation to device independent color correction. It is to be understood that a MLP is just one type of well known neural network. Furthermore, where a neural network is specified in herein, a MLP or other type of neural network may be utilized.

10 A single-illuminant color correction using an MLP.

As discussed above, when a color correction using a TRC-matrix model (Figure 1) cannot be accurate even under one fixed known illuminant, the cause is likely to be non-ideality, nonlinearity or structural complexity in the electronic camera. A neural network as shown in Figure 4A or a MLP model as shown in Figure 4B can be used instead of the TRC-matrix model to improve the correction accuracy. In Figure 4A any neural network may be utilized, for example, the MLP of Figure 4b. With the neural network (e.g., MLP) model, the correction can be based on one fixed illuminant, thus hereinafter referred to as "single-illuminant" color correction. A color correction model using a neural network (e.g., MLP) had been used only for imaging devices such as printers, whose color transformation is highly nonlinear and whose white point (corresponding to the color of illumination in case of an electronic camera) is considered fixed.

25 A Y input 1, a C input 2 and a C input 3 provide image data to neural network 4 as shown in Figure 4A. Image data is provided from an electronic camera. Alternatively, image data may be provided to inputs 1, 2 and 3 from a reproducing apparatus and/or a transmission medium. In the latter instances, since illumination

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information necessary for color correction is only available from the electronic camera, such illumination information should be recorded and/or transmitted with the image data, or should otherwise be provided to the neural network 4. In the case of transmission or
5 recording of image data from an electronic camera, many image data formats include unused fields or spaces for use by image printers. Such fields or spaces are typically available to record the date of a photo shoot, a camera model designation or a camera manufacturer designation. Therefore, one or more unused field or space may be
10 allocated to illumination information, such that the image data is recorded and/or transmitted together with the illumination information, but before any color correction has been applied to the image data.

The neural network 4 provides an X output 5, a Y output 6 and a Z output 7 in the colorimetric space XYZ. As shown in Figure
15 4B, the MLP has three input nodes, Y, U and V, designated by reference numerals 11, 12 and 13, respectively, for camera's output values (RGB or YCC). The MLP also has three output nodes X, Y and Z, designated by reference numerals 14, 15 and 16, respectively. Output nodes X, Y and Z provide either colorimetric
20 values (XYZ or $L^*a^*b^*$) for device-independent color correction, or target output values in RGB or YCC for device-specific color correction. These colorimetric or color-corrected output values may be provided to image output devices, such as printers or display
25 monitors, via the output device's characterization model. The values may also be directly provided to image output devices. Alternatively, these values, encoded and/or compressed versions thereof, may be recorded by a recording apparatus onto a recording medium such as a magnetic disc, an optical disc, a magneto-optical
30 disc, or a sold state memory, or may be transmitted through a

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transmission medium such as the Internet, telephone lines, dedicated lines, radio frequency or an optical medium.

For optimizing an MLP's parameters, a set of input-output samples, called a "training" data set, is prepared that includes
5 representative color samples, pairs of inputs YUV and desired outputs XYZ. Then a given task is formulated as a nonlinear least squares problem, in which, the objective is to optimize an MLP's parameters by minimizing a squared error measure between the desired outputs and the model's outputs.

10 The objective function $E(\cdot)$, the squared error measure, can be expressed by residual vectors $r(\theta)$ as:

$$E(\theta) = (1/2)r^T(\theta)r(\theta)$$

The parameter optimization is carried out iteratively with the aim of eventually making the model reproduce the desired outputs. This
15 iterative process is referred to as "training" (or "learning") in the neural network literature.

Besides the "training" data set, an MLP's approximation capacity is often measured by using a different data set, called a
"checking" data set, which is not employed for parameter
20 adjustment. One important advantage of neural networks, and in particular, those of an MLP, are the results obtained for input data outside of the training data set.

In the posed "device-independent" color correction problem, the MLP is trained to form a mapping from a camera's response
25 signals (e.g., RGB or YCC) to colorimetric values (e.g., XYZ or $L^*a^*b^*$). In the "device-specific" color correction problem, the MLP's desired mapping is from error-corrupted camera's response signals (RGB or YCC) to their associated corrected RGB or YCC signals. In any event, those input-output samples are collected by
30 using the standard Macbeth ColorChecker or Munsell color patches, which are evenly distributed in the entire color space.

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Note that if the data are collected under a certain single illuminant, then the task becomes the so-called single-illuminant problem, which is ubiquitous in color correction for images captured by image scanners.

5 Multi-illuminant color correction using an MLP

Referring now to Figure 5, an MLP model is used to achieve an automatic color correction for images captured by an electronic camera under arbitrary illuminant (at the time of image capture). The MLP model is trained so that it automatically adjusts its mapping, an
10 inverse function of the camera in a case of device-independent correction, depending on the illuminant used at the time of image capture. This is hereinafter referred to as "multi-illuminant" color correction. Since it is difficult to exactly know what illuminant was used at the time of image capture, the model instead takes
15 advantage of the electronic camera's on-camera illumination estimation data (or white balancing data), R/G and B/G values for instance, where R, G, and B are measured signal values for illumination color, as illustrated in the upper portion of Figure 5. In Figure 5 "Pana white" refers to a trademark for a "white" fluorescent
20 bulb sold in Japan by Matsushita Electric Industrial Co. Ltd. of Osaka, Japan. "Mellow d" refers to a trademark which identifies a "daylight" type of fluorescent bulb sold in Japan by Toshiba Lighting & Technology Co. of Tokyo, Japan. It is to be understood that Figure 13 can be used in place of the upper portion of Figure 5
25 (White balance plane)

The MLP used for the multi-illuminant color correction should have additional nodes to input the illumination information. For instance, two additional input nodes can be used because illumination chromaticity can be described by a set of two values.
30 Consequently, the MLP model for this task has five input nodes B/G,

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R/G, Y, U and V, designated by reference numbers 17, 18, 19, 20 and 21, respectively, and three output nodes X, Y and Z, designated by reference numerals 22, 23 and 24, respectively, as shown in Figure 5. The outputs X, Y and Z, or transformed, normalized, encoded and/or compressed versions thereof, may be recorded by a recording apparatus onto a recording medium such as magnetic disc, an optical disc, a magneto-optical disc, or a solid state memory or may be transmitted through a transmission medium such as the Internet, telephone lines, dedicated lines, radio frequency or an optical medium.

In accordance with one embodiment of the invention, the following steps are taken to train a multi-illuminant color correction model:

- (1) Measure an electronic camera's output values and colorimetric values (for device-independent correction) of a set of color samples under several representative illuminants. The total size of training data set is therefore $N \times M$, where N is the number of color samples and M is the number of representative illuminants under consideration.
- (2) For each illuminant, measure gain data of the RGB channels as applied to balance white, or instead, measure signal values of RGB channels for illuminant color.
- (3) Convert the measured three values onto a set of two chromaticity values, for instance, R/G and B/G. The data may be further processed to better characterize the illuminant information, as described below with respect to a method for constructing fuzzy membership functions for the CANFIS neuro-fuzzy model.

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- (4) An MLP is trained using the data set (1), as described above. At the same time, the data set (3), that is, the illuminant information under which data (1) is measured, are provided to the input nodes 17 (B/G) and 18 (R/G).

5

After the above described steps have been completed, the MLP model outputs the original scene's colorimetric values by having camera's output values and the illuminant information at its input. The camera's illuminant dependency of color transformation is automatically compensated by referring to the illumination information. When the illuminant actually used at the time or times of image capture does not coincide to any of the representative illuminants used for the MLP training, the MLP automatically approximates the inverse function of the camera's color transformation between illuminants.

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Method for training MLP models

Due to the nonlinearity of MLPs, an efficient iterative method is desirable for solving the NN nonlinear least squares problem posed in above section. Numerical tests have revealed that a dogleg trust-region implementation of the Levenberg-Marquardt-type algorithm is suitable for the problem to be solved. In further detail, dogleg methods produce an efficient piecewise linear approximation of the restricted Levenberg-Marquardt step within the trust region.

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Figures 6A and 6B illustrate how the dogleg step approximates the trust region step over a two dimensional subspace spanned by the Cauchy step and the Newton (or Gauss-Newton) step. The crosspoint between the piecewise linear dogleg trajectory (highlighted in Figure 6A) and the trust-region boundary yields one of

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the next three steps:

1. Restricted Cauchy step:

$$S_{RC} \stackrel{\text{def}}{=} -R_{\text{now}} \frac{g_{\text{now}}}{\|g_{\text{now}}\|}$$

when the trust radius R_{now} is smaller than the length of the Cauchy step S_{Cauchy} , which is given by

$$S_{\text{Cauchy}} \stackrel{\text{def}}{=} -\frac{g_{\text{now}}^T g_{\text{now}}}{g_{\text{now}}^T H_{\text{now}} g_{\text{now}}} g_{\text{now}}$$

5 where g and H denote the gradient vector and the Hessian matrix, respectively.

2. Newton step:

$$S_{\text{Newton}} \stackrel{\text{def}}{=} -H_{\text{now}}^{-1} g_{\text{now}}$$

when the trust radius is larger than or equal to the length of the Newton step.

10 3. Dogleg step:

$$S_{\text{Dogleg}} \stackrel{\text{def}}{=} S_{\text{Cauchy}} + h_{\text{now}}(S_{\text{Newton}} - S_{\text{Cauchy}})$$

when the trust radius is in between the Cauchy step and the Newton step. One of those steps is employed at each iteration for optimizing the model by the iterative scheme:

$$\theta_{\text{next}} = \theta_{\text{now}} + \eta d ,$$

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where d is a direction vector and η is some positive step size regulating to what extent to proceed in that direction. The parameter h in Figure 6A can be determined in a straightforward calculation:

$$h_{now} = \frac{R_{now}^2 - S_{Cauchy}^T S_{Cauchy}}{(S_{Newton} - S_{Cauchy})^2 S_{Cauchy} + \sqrt{p_{now}}}$$

5 where

$$p_{now} = (S_{Newton} - S_{Cauchy})^T (S_{Newton} - S_{Cauchy}) R_{now}^2 + (S_{Newton}^T S_{Cauchy})^2 - (S_{Newton}^T S_{Newton})(S_{Cauchy}^T S_{Cauchy})$$

10 The power of the dogleg trust-region strategy resides in ease for a smooth transition between the steepest descent method (global convergence property) and Newton's method (fast local convergence property), making the algorithm very robust. For instance, when a next step is not satisfactory, the dogleg algorithm shortens the step length and deflects it towards the steepest descent direction simultaneously and efficiently based on a simple trust-region control.

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Table 1 below compares the convergence speed of three representative nonlinear optimization algorithms in a single-illuminant (D65-illuminant) problem:

	25 training data	51 checking data	Stopped epoch
1D-lookup table with a 3 x 3 matrix transformation	0.015900	0.025576	N/A
MLP with 7 hidden units by steepest descent- based pattern-by-pattern learning	0.005792	0.016862	1,000,000 (10,818.61 sec.)
MLP with 10 hidden units by steepest descent- based pattern-by-pattern learning	0.004608	0.015991	1,000,000
MLP with 7 hidden units by Polak-Ribiere conjugate gradient batch learning	0.005797	0.018310	2,400 (114.65 sec.)
MLP with 10 hidden units by Polak-Ribiere conjugate gradient batch learning	0.004519	0.016344	2,000
MLP with 7 hidden units by a dogleg-driven Levenberg-Marquardt learning	0.00552	0.017947	44 (8.54 sec.)

TABLE 1

The performance comparison is in root mean squared error of scaled XYZ values between the TRC-matrix oriented model and the MLP models with three representative learning algorithms. Note in the last column "Stopped epoch" that the required execution time (in seconds) is shown parenthesized only the for (3 x 7 x 3) MLP models with seven hidden units. From Table 1 it is clear that for a single-illuminant color correction problem, the use of the dogleg driven Levenberg-Marquardt converges faster than the other tested learning techniques indicated in Table 1. Such performance comparison is further discussed in *Color device characterization of*

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5 *electronic cameras by solving adaptive networks nonlinear least squares problems*, Eiji Mizutani (a co-inventor of the present application), Kenichi Nishio (the other co-inventor of the present application), Naoya Katoh and Michael Blasgen, 8th IEEE International Conference on Fuzzy Systems (FUZZ-IEEE'99), Seoul, Korea, August 22-25, 1999, which paper and the figures therein are hereby incorporated by reference. Furthermore, the dogleg trust-region algorithms are further discussed in *Computing Powell's Dogleg Steps for Solving Adaptive Networks Nonlinear Least-Squares Problems*, Eiji Mizutani (a co-inventor of the present application), 8th International Fuzzy Systems Association World Congress (IFSA'99), Hsinchu, Taiwan, August 17-20, 1999, and in *Powell's dogleg trust-region steps with the quasi-Newton augmented Hessian for neural nonlinear least-squares learning*, Eiji Mizutani (a co-inventor of the present application), The IEEE International Conference on Neural Networks, Washington D.C., July 10-16, 1999, both of which papers and the figures therein are hereby incorporated by reference.

20 Referring now to Figure 7, such Figure illustrates a comparison in color difference under a D65 illuminant between a single MLP approach and a conventional look-up table based (TRC-matrix) approach. Note that all 25 color differences (for 24 Macbeth color checkers and a "perfect-black" color sample) must be smaller than 10. Figure 7 clearly illustrates an MLP based method effectively reduces the color difference down below an upper-limit threshold value (set equal to 10) for all 25 color samples under the D65 illuminant, whereas a conventional look-up-table based (TRC matrix) method failed to do so.

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Multi-illuminant color correction using a CANFIS neuro-fuzzy model

A CANFIS neuro-fuzzy model is specially designed to perform automatic "multi-illuminant" color correction based on problem-specific knowledge, which is represented by a collection of fuzzy if-then rules: In particular, "IF-part" is expressed by fuzzy membership functions (MFs) and "THEN-part" is constructed by local-expert MLPs. This is the so-called "CANFIS with neural rules" model.

In particular, four fuzzy rules are specified in accordance with fuzzy-partitioning on the two-dimensional transformed white balance plane, as explained below in relation to a method for constructing fuzzy membership functions. The resulting CANFIS neuro-fuzzy model consists of four fuzzy MFs (two for each axis) and four associated local-expert MLPs, as illustrated in Figure 8. The input vector is split into two vectors for IF-part (MFs) and THEN-part (MLPs):

1. Two inputs of on-camera illumination information fed into fuzzy MFs;
2. Three inputs of camera's output signals (e.g., YUV) fed into local-expert MLPs.

The CANFIS model computes a weighted sum of the outputs of local-expert MLPs as the final output vector A (e.g., X, Y, Z color signals) by

$$A = \sum_{i=1}^4 g_i O_i$$

where g_i and O_i are the i -th firing strength and the i -th MLP's output vector, respectively. Each firing strength, given by the product of IF-part MF outputs, represents the extent to which the associated THEN-part MLP affects the final output. In this context, a set of IF-

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part MFs plays a role as an integrating unit that combines the outputs of fired THEN-part MLPs.

Usually, the integrating unit is composed of bell-shaped differentiable fuzzy MFs and their neighboring MFs are set up to have sufficient overlap. Hence, all of the associated local-expert MLPs function complementarily to generate the final output in the equation for the value of A. On the other hand, if the integrating unit is constructed by non-overlapped rectangular MFs resulting in a switching unit, then only a single local-expert MLP contributes to the final output. Only one of the g_i values becomes a "unit" with all of the others being "zero." Such a single non-zero g_i is associated with the i-th "fired" local expert MLP. In other words, local expert MLPs function competitively rather than complementarily. Stated differently, the CANFIS concept basically resides in the synergism among fuzzy MFs and local-expert MLPs, ruling out such an extreme switching case.

The CANFIS model has an advantage in that without increasing the number of fuzzy MFs (so that fuzzy rules can be held to meaningful limits), the model can increase learning capacity just by applying an appropriate architectural or algorithmic modification solely to the local-expert MLPs. For instance, such modification can simply adjust the number of MLP hidden nodes/layers. It should be noted that the CANFIS model can be viewed as a local-tuning RBFN (Radial Basis Function Network) model when the hidden layers of THEN-part MLPs are eliminated. Hence, the CANFIS model can be regarded as a generalized local-tuning neural network.

Its disadvantages might be slower learning due to architectural complexity and a requirement of larger training data, compared with a single MLP model. Therefore, if the task has a small limited number of training data, then an MLP model might be a better choice. Experimental results obtained with the CANFIS model are

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presented below in relation to a method for training a CANFIS neuro-fuzzy model for multi-illuminant color correction.

The CANFIS with linear rules model is equivalent to the well-known Takagi-Sugeno (also called "TSK" or "Sugeno-type") fuzzy inference model. In the field of control engineering, where a quick response is important, this TSK model is by far the most commonly used fuzzy system. The quickness comes from a computational advantage since implementation of linear rules is much simpler than implementation of nonlinear rules.

CANFIS modeling and CANFIS with linear rules are explained in detail at pages 369-400 and 572-592, of the text *Neuro-Fuzzy and Soft Computing, A Computational Approach to Learning and Machine Intelligence*, by Jyh-Shing Roger Jang, Chuen-Tsai Sun and Eiji Mizutani (co-inventor of the present application), Prentice Hall, Upper Saddle River, New Jersey 07458, 1997, third printing, which pages and the figures therein are hereby incorporated by reference.

Method for constructing fuzzy membership functions for multi-illuminant color correction using the CANFIS neuro-fuzzy model described above.

Fuzzy Partitioning

In the CANFIS neuro-fuzzy model, fuzzy membership functions (MFs) partition the MF-input space into several local-expert's territories. Hence, data that come close to the center of a certain local-expert's area may not affect very much to the parameter-updatings of the other local experts. This local-tuning mechanism can make "local experts" learn locally optimal mainly for the vicinity of their own local regions.

For the multiple-illuminant problem as illustrated in Figure 9, data in the halogen illuminant region should not make a significant impact on a local-expert MLP in the D90-illuminant region, which is

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at the other end of the "natural-illuminant" curve on the white balance plane. Those two extreme regions must be somehow distinguished by an appropriate partitioning. Fuzzy MFs plays an important role in partitioning the illuminant territories on the white balance plane in a "fuzzy" (but not "crisp") fashion, as illustrated in Figure 10. In Figure 10, two representative illuminants, halogen and D65, are chosen to determine the initial center positions of the two MFs on the X-axis, which corresponds to the "natural-illuminant" curve. This implies that the location along that curve is selected as an important feature in the task. The two linguistic labels "A1" and "A2" on the X-axis in Figure 10 signify the respective "Halogen" and "D65" where:

The value/degree of A1-MF shows how close the illuminant is to the "Halogen" illuminant; and

The value/degree of A2-MF shows how close the illuminant is to the "D65" illuminant.

Clearly, only one feature may not be sufficient for describing each illuminant's region appropriately. Another important feature is the distinction between the "natural" and the "fluorescent" illuminants. Therefore, two corresponding MFs (B1 for "fluorescent" and B2 for "natural") are constructed on the Y-axis to represent closeness to the fluorescent and natural illuminants, where:

The B1-MF value shows how close to the "fluorescent" illuminant-curve; and

The B2-MF value shows how close to the "natural" illuminant-curve.

In this way, each of mixed illuminants along the "mixtures" curve in Figure 9 can be characterized by the degree of membership to the "natural" or "fluorescent" illuminant, as would be the case where an illuminant consisted of a 40 % natural illuminant and a 60 % fluorescent illuminant. In Figure 9, "Lupica ace" refers to a

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trademark which identifies a "neutral" type of fluorescent bulb sold in Japan by Mitsubishi Electric Co. of Tokyo, Japan. Since the X and Y axes in Figures 9 and 10 are not the same, a certain "nonlinear" coordinate transformation is needed. Such coordinate transformation is described below.

Nonlinear Coordinate Transformation on the White-Balance Plane

Figure 11 shows an actual data distribution of experimental data sets on the original R/G-B/G white balance plane. To conform Figure 11 to Figure 10, it is necessary to introduce an appropriate coordinate transformation. First, a simple linear-scaling is applied, resulting in Figure 12. Then a neural network nonlinear coordinate transformation is applied, yielding Figure 13, where Figure 13 has Cartesian coordinates that match those of Figure 10, although many other nonlinear transformations are possible.

The importance of nonlinear coordinate transformation cannot be overemphasized because it allows simple "grid" partitionings. There are several advantages over "scatter" partitionings as are typically formed by a radial basis function network ("RBFN"). RBFNs are explained in detail at pages 238-246 and 369-400, and in particular, at Figure 13.3 on page 373 of said text *Neuro-Fuzzy and Soft Computing, A Computational Approach to Learning and Machine Intelligence*, which pages and the figures therein are hereby incorporated by reference.

In further detail, nonlinear coordinate transformation provides the following advantages:

1. Linguistic interpretability can be kept sufficiently high to match our intuitive understandings; and
2. The required number of (basis) functions can be reduced.

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Advantage #1 insinuates that clear linguistic labels may not be readily put on each MF in the case of scatter or tree partitionings. Advantage #2 indicates, for instance, that in order to form nine local regions on the X-Y plane, the RBFN needs nine basis functions, whereas the CANFIS model requires six MFs (three MFs for each axis). Accordingly, the total number of function parameters differs. Further detail regarding partitioning is taught at pages 86 and 87 of said *Neuro-Fuzzy and Soft Computing, A Computational Approach to Learning and Machine Intelligence*, which pages and the figures therein are hereby incorporated by reference.

Method for training a CANFIS neuro-fuzzy model for multi-illuminant color correction.

Many nonlinear optimization algorithms can be employed for training the CANFIS neuro-fuzzy model described above in relation to a multi-illuminant color correcting using a CANFIS neuro-fuzzy model. The model consists of two major parameterized constituents:

- (1) "fuzzy MFs (IF-part);"" and
- (2) "local-expert MLPs (THEN-part),"

as illustrated in Figure 8. There are many possibilities in applying optimization algorithms to update the parameters of these two constituents, for example:

(Method A) Apply the same optimization algorithm to both IF-part MFs and THEN-part MLPs; or

(Method B) Apply different optimization algorithms to IF-part MFs and THEN-part MLPs.

These methods can be implemented in either a system-wise or a component-wise manner. For system-wise training, all components, MFs and MLPs, of the CANFIS neuro-fuzzy model are trained simultaneously as a system, whose final output is computed by the

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above equation for the value of A as set forth above. For component-wise training, each MF or MLP is tuned/trained independently, and then all the components are put together to form the CANFIS neuro-fuzzy model, whose final output is computed by the above equation for the value of A as set forth above.

To be more specific by referring to Figure 8, in the component-wise manner, each local expert MLP is usually trained to produce the desired final output vector A (i.e., X, Y, Z) as the output vector O_i . On the other hand, in the system-wise training manner, the final output vector A (as set forth above) is attempted to be made to match the desired triplet X, Y and Z, but each local expert MLP's output vector O_i may not be necessarily close to it; that is, each output vector O_i may not be interpretable. In Figure 8, the three output nodes of each local expert MLP are tagged by X, Y and Z, merely for the purpose of showing which node is related to which signal.

Furthermore, there are three different parameter-updating modes, depending on treatment of training data:

- (1) online pattern-by-pattern updating mode;
- (2) block-by-block updating mode; and
- (3) batch updating mode.

Therefore, there are many possible applications of any optimization algorithms to the CANFIS model. It is worth noting, however, that regardless of whether Method A or Method B is utilized, the component-wise training is questionable in obtaining highly accurate results because local-expert MLPs' outputs are optimized independently of the firing strengths of fuzzy MFs in spite of the dependence expressed in the above equation for the value of A as set forth above. Thus, the other system-wise training is of much greater practical importance, especially when the CANFIS model

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needs to produce very accurate input/output mappings, as required in color correction of color images.

In general, an important observation can be made in neuro-fuzzy systems that the parameters of MLPs are far from optimal values, compared with those of MFs, because the initial parameters of fuzzy MFs are determined based on problem-specific knowledge, whereas the initial parameters of local-expert MLPs are randomly initialized. Therefore, application of different optimization algorithms to MFs and MLPs (i.e., implementation of Method B) is possible; in particular, application of a faster algorithm to MLPs and a slower algorithm to MFs. A typical demonstration in this spirit is the hybrid-learning of ANFIS (i.e., single-output CANFIS with linear rules model), a combination of fast "linear" least squares and a slow steepest descent-type method, although it is restricted to "linear" consequent fuzzy systems. Such hybrid-learning is detailed at pages 219-220 and 222-223 of said text *Neuro-Fuzzy and Soft Computing, A Computational Approach to Learning and Machine Intelligence*, supra, which pages and the figures therein are hereby incorporated by reference.

Method A in the system-wise training manner can be considered in the same spirit for the CANFIS with neural rules model; for instance, by applying the steepest descent-type method to MFs in the "batch" mode and it to MLPs in the "online pattern-by-pattern" mode. This strategy can be improved in conjunction with a simple heuristic rule; for instance:

Rule: Fix the parameters of fuzzy MFs at an early stage of training phase.

Table 2 shows four representative results obtained with MLP and CANFIS models, when the checking error was minimized or at the preset limit iteration of 2,000,000. The column "# of Para." refers to the number of parameters and "RMSE" refers to the root

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mean squared error. The columns labelled "# of bad samples" are most important, denoting the number of color samples whose color differences were greater than the upper-limit threshold value (set equal to 10). All of the four models were trained by using the

5 widely-employed steepest descent-type method in the online pattern-by-pattern updating mode.

Exp. #	Structure	# of Para.	Stopped epoch	Training XYZ-RMSE	Average color diff.	# of bad samples	Checking XYZ-RMSE	Average color diff.	# of bad samples
1	5 x 22 x 3 MLP	201	148,500	0.006176	3.09685	13	0.005781	2.88622	52
2	5 x 45 x 3 MLP	408	347,500	0.005044	2.57207	11	0.004601	2.29206	39
3	CANFIS (HU = 10)	304	2,000,000	0.006356	2.85213	7	0.006688	2.80347	35
4	CANFIS (HU = 10)	304	1,771,000	0.005476	2.52347	0	0.005542	2.44866	0

TABLE 2

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The results in Experiment #4 were obtained by using the following heuristic rule:

Rule: Start updating the parameters of fuzzy MFs after 500,000 epochs.

5 Selection of output color space

 In the present disclosure, XYZ space is mainly used as an output color space of color correction models. As described earlier herein, the output color space can also be $L^*a^*b^*$ or $X_nY_nZ_n$ (normalized XYZ space) for device-independent color correction. For
10 device-specific color correction, it can be any color space that the color imaging device subject to the color correction outputs, or can even be a color space arbitrarily defined according to a user's specific requirement. The change of output color space can be achieved by simply replacing the target output data for color
15 correction model's training data set.

 As discussed above in relation to Illuminant dependency, an electronic camera's output values are white-balanced to keep $R=G=B$ at illuminant color. $X_nY_nZ_n$ and $L^*a^*b^*$ color spaces also have a similar operation in their definition, wherein tri-stimulus
20 values are normalized by values for illuminant color. Such a color space can be denoted as a normalized color space. This operation represents the human eye's chromatic adaptation.

 As shown in Figure 1, an electronic camera's output values are based on gamma-corrected RGB. Similar operations are found in
25 the definition of $L^*a^*b^*$ color space, and such a color spaces can be considered to be a nonlinear color space. The nonlinear mapping is for a correlation with lightness (a measure for human's luminance perception), to better describe perceived color by human eyes rather than the physical property of color.

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5 A non-normalized linear color space, such as XYZ, can provide an advantage when used as a multi-illuminant color correction model's output color space. An image captured by an electronic camera may have incorrect white point, due to incorrect estimation of illumination automatically made on the camera. For such a case, white point correction can be readily made off the camera after capturing the image, if the color correction model's output space is XYZ. If the output space is a nonlinear color space, white point correction is more complicated because the output data has to be
10 once brought into a linear space to perform the white point correction.

It can be assumed that an electronic camera's color transformation is a function of its white-balance setting, as described above in relation to illuminant dependency. No matter
15 how correct or incorrect the on-camera estimation of illumination is, the camera's color transformation can be uniquely determined by referring to the camera's white-balance information, R/G and B/G for instance. Therefore, XYZ values that output from a multi-illuminant color correction model can well describe the original color's physical property, even if the input image's white point is incorrect. When a
20 user determines that the white point is incorrect in an image taken by an electronic camera, the user can first output image data in XYZ from the multi-illuminant color correction model, then can re-estimate the image's illumination using a sophisticated method, which is too computationally expensive to be performed on-camera. The method
25 can provide accuracy not only in white point, but also in color distributed around the re-balanced white point, because the re-balancing is applied to image data in corrected color space. A non-normalized linear color space can also be a space formed at an
30 image sensor's output (raw image data).

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Color constancy

It is known that many users prefer an electronic camera that reproduces color as if images were captured under one fixed standard illuminant such as D50 (specified by CIE, 5000K daylight),
5 no matter what illuminant is actually used at the image capturing. This is referred to as "color constancy" color reproduction. By appropriately modifying the training data set of the above described multi-illuminant color correction model using either an MLP or a CANFIS neuro-fuzzy architecture, the above described "color-
10 constancy" color correction is easily accomplished.

It is to be understood that although an MLP is described as one example of a neural network which is applicable to the present invention, other types of neural networks such as a radial basis function network ("RBFN") or a modular neural network may also be
15 utilized.

It is to be further understood that each embodiment of the present invention may be implemented as software to be run on a computer or may be implemented as a function of image processing software run on a computer. In such an instance, image data files
20 may be opened by the software, and any embodiment of the present invention may be applied to image data, such as a JPEG, GIF or BMP format file to allow color correction to be applied to such image data.

It is additionally to be understood that the methods and apparatus of the present invention may be applied to characterize a component in a color imaging device, such as an image sensor in an electronic camera. It is to be further understood that such
25 characterization may be employed to correct for undesired qualities of such image sensor.

Although only certain embodiments have been described in
30 detail, those having ordinary skill in the art will certainly understand

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that many modifications are possible without departing from the teachings hereof. All such modifications are intended to be encompassed within the following claims.

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We claim:

1. A method of correcting color of a color image obtained by an electronic camera, comprising the steps of:
 - determining, using a neural network, a correction to data representative of the color image based upon an estimated illuminant of the color image; and
 - applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.
2. The method of claim 1, wherein the electronic camera captures at least one still image.
3. The method of claim 1, wherein the electronic camera captures a succession of moving images.
4. A method of correcting color of a color image obtained by an electronic camera, comprising the steps of:
 - determining, using a multilayer perceptron model, a correction to data representative of the color image based upon an estimated illuminant of the color image; and
 - applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.
5. The method of claim 4, wherein the electronic camera captures at least one still image.
6. The method of claim 4, wherein the electronic camera captures a succession of moving images.

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7. The method of claim 4, wherein the multilayer perceptron model is trained based upon a dogleg trust region implementation of a Levenberg-Marquardt type algorithm.

5 8. The method of claim 4, further comprising the step of:
outputting an output color space of the color corrected
image as a space not normalized with chromaticity
coordinates the sources of illumination.

9. The method of claim 4, further comprising the step of:
using training data of each neural network as a
10 colorimetric value under a standard source of illumination.

10. A method of correcting color of a color image obtained
by an electronic camera, comprising the steps of:
determining, using a coactive neuro-fuzzy inference
system model, a correction to data representative of the color
15 image based upon an estimated illuminant of the color image;
and
applying the correction to the data representative of the
color image, wherein the illuminant comprises multiple sources
of illumination.

11. The method of claim 10, wherein the electronic camera
20 captures at least one still image.

12. The method of claim 10, wherein the electronic camera
captures a succession of moving images.

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13. The method of claim 10, wherein an integrating unit comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of color image capture.

5 14. The method of claim 13, further comprising the step of:
 constructing fuzzy membership functions by applying a
 neural network nonlinear coordinate transformation to a white
 balance plane in order to characterize estimated illumination
 for the coactive neuro-fuzzy inference system model.

10 15. The method of claim 10, further comprising the step of:
 training the coactive neuro-fuzzy inference system
 model by constructing fuzzy membership functions generated
 by applying a neural network nonlinear coordinate
15 transformation to a white balance plane in order to
 characterize estimated illumination for the coactive neuro-
 fuzzy inference system model.

 16. The method of claim 13, further comprising the step of:
 training the coactive neuro-fuzzy inference system
 model by constructing fuzzy membership functions generated
20 by applying a neural network nonlinear coordinate
 transformation to a white balance plane in order to
 characterize estimated illumination for the coactive neuro-
 fuzzy inference system model, wherein all parameters of fuzzy
 membership functions and local expert multilayer perceptrons
25 are updated simultaneously.

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17. The method of claim 13, further comprising the step of:
training the coactive neuro-fuzzy inference system
model by constructing fuzzy membership functions generated
by applying a neural network nonlinear coordinate
transformation to a white balance plane in order to
characterize estimated illumination for the coactive neuro-
fuzzy inference system model, wherein all parameters of fuzzy
membership functions and local expert multilayer perceptrons
are updated simultaneously in conjunction with a heuristic
parameter updating rule.

18. The method of claim 13, 14, 15, 16 or 17, wherein at
least two of the fuzzy membership functions overlap.

19. A method of correcting color of a color image obtained
by an electronic camera, comprising the steps of:
determining, using a coactive neuro-fuzzy inference
system with a switching unit, a correction to data
representative of the color image based upon an estimated
illuminant of the color image.

20. The method of claim 10, further comprising the steps
of:
finding a color conversion inverse map using separate
neural networks associated with respective representative
sources of illumination; and
outputting an output color space of the color corrected
image as a space not normalized with chromaticity
coordinates the sources of illumination.

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21. The method of claim 10, further comprising the steps of:

5 finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and

outputting an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

10 22. The method of claim 10, further comprising the steps of:

finding a color conversion inverse map using separate neural networks associated with respective representative sources of illumination; and
15 using training data of each neural network as a colorimetric value under a standard source of illumination.

23. The method of claim 10, further comprising the steps of:

20 finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and
using training data of each neural network as a colorimetric value under a standard source of illumination.

24. An apparatus for correcting color of a color image obtained by an electronic camera, comprising:
25 a neural network for determining a correction to data representative of the color image based upon an estimated illuminant of the color image and for applying the correction to

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the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

25. The apparatus of claim 24, wherein the electronic camera captures at least one still image.

5 26. The apparatus of claim 24, wherein the electronic camera captures a succession of moving images.

27. An apparatus for correcting color of a color image obtained by an electronic camera, comprising:

10 a multilayer perceptron model for determining a correction to data representative of the color image based upon an estimated illuminant of the color image, and for applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

15 28. The apparatus of claim 27, wherein the electronic camera captures at least one still image.

29. The apparatus of claim 27, wherein the electronic camera captures a succession of moving images.

20 30. The apparatus of claim 27, wherein the multilayer perceptron model is trained based upon a dogleg trust region implementation of a Levenberg-Marquardt type algorithm.

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31. The apparatus of claim 27, wherein the multilayer perceptron model outputs an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

5 32. The apparatus of claim 27, wherein the multilayer perceptron model uses training data of each neural network as a colorimetric value under a standard source of illumination.

33. An apparatus for correcting color of a color image obtained by an electronic camera, comprising:

10 a coactive neuro-fuzzy inference system model for determining a correction to data representative of the color image based upon an estimated illuminant of the color image, and for applying the correction to the data representative of the color image, wherein the illuminant comprises multiple
15 sources of illumination.

34. The apparatus of claim 33, wherein the electronic camera captures at least one still image.

35. The apparatus of claim 33, wherein the electronic camera captures a succession of moving images.

20 36. The apparatus of claim 33, wherein an integrating unit comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of color image capture.

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37. The apparatus of claim 36, wherein fuzzy membership functions are constructed by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

38. The apparatus of claim 33, wherein the coactive neuro-fuzzy inference system model is trained by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

39. The apparatus of claim 36, wherein the coactive neuro-fuzzy inference system model is trained by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously.

40. The apparatus of claim 36, wherein the coactive neuro-fuzzy inference system model is trained by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously in conjunction with a heuristic parameter updating rule.

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41. The apparatus of claim 36, 37, 38, 39 or 40, wherein at least two of the fuzzy membership functions overlap.

42. An apparatus for correcting color of a color image obtained by an electronic camera, comprising:

5 a coactive neuro-fuzzy inference system with a switching unit for determining a correction to data representative of the color image based upon an estimated illuminant of the color image.

10 43. The apparatus of claim 33, wherein coactive neuro-fuzzy inference system model finds a color conversion inverse map using separate neural networks associated with respective representative sources of illumination, and outputs an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

15 44. The apparatus of claim 33, wherein coactive neuro-fuzzy inference system model finds a color conversion inverse map using neural networks associated with respective representative sources of illumination, and outputs an output color space of the color corrected image as a space not normalized with chromaticity
20 coordinates the sources of illumination.

25 45. The apparatus of claim 33, wherein coactive neuro-fuzzy inference system model finds a color conversion inverse map using separate neural networks associated with respective representative sources of illumination, and uses training data of each neural network as a colorimetric value under a standard source of illumination.

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5 46. The apparatus of claim 33, wherein coactive neuro-fuzzy inference system model finds a color conversion inverse map using neural networks associated with respective representative sources of illumination, and uses training data of each neural network as a colorimetric value under a standard source of illumination.

10 47. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:
 determining, using a neural network, a correction to data representative of the color image based upon an estimated illuminant of the color image;
 applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and
15 recording on the recording medium data representative of the corrected data.

 48. The recording medium 47, wherein the electronic camera captures at least one still image.

20 49. The recording medium of claim 47, wherein the electronic camera captures a succession of moving images.

 50. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:
25 determining, using a multilayer perceptron model, a correction to data representative of the color image based upon an estimated illuminant of the color image;

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applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and

5 recording on the recording medium data representative of the corrected data.

51. The recording medium of claim 50, wherein the electronic camera captures at least one still image.

52. The recording medium of claim 50, wherein the electronic camera captures a succession of moving images.

10 53. The recording medium of claim 50, wherein the multilayer perceptron model is trained based upon a dogleg trust region implementation of a Levenberg-Marquardt type algorithm.

54. The recording medium of claim 54, further comprising the step of:

15 outputting an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

55. The recording medium of claim 50, further comprising the step of:

20 using training data of each neural network as a colorimetric value under a standard source of illumination.

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56. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:

- 5 determining, using a coactive neuro-fuzzy inference system model, a correction to data representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and
- 10 recording on the recording medium data representative of the corrected data.

57. The recording medium of claim 56, wherein the electronic camera captures at least one still image.

58. The recording medium of claim 56, wherein the

15 electronic camera captures a succession of moving images.

59. The recording medium of claim 56, wherein an integrating unit comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of

20 color image capture.

60. The recording medium of claim 59, further comprising the step of:

- constructing fuzzy membership functions by applying a neural network nonlinear coordinate transformation to a white
- 25 balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

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61. The recording medium of claim 56, further comprising the step of:

5 training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

10 62. The recording medium of claim 59, further comprising the step of:

15 training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously.

20 63. The recording medium of claim 59, further comprising the step of:

25 training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously in conjunction with a heuristic parameter updating rule.

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64. The recording medium of claim 59, 60, 61, 62 or 63, wherein at least two of the fuzzy membership functions overlap.

65. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:

5 determining, using a coactive neuro-fuzzy inference system with a switching unit, a correction to data representative of the color image based upon an estimated illuminant of the color image; and
10 recording on the recording medium data representative of the corrected data.

66. The recording medium of claim 56, further comprising the steps of:

15 finding a color conversion inverse map using separate neural networks associated with respective representative sources of illumination; and
outputting an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

20 67. The recording medium of claim 56, further comprising the steps of:

finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and
25 outputting an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

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68. The recording medium of claim 56, further comprising the steps of:

5 finding a color conversion inverse map using separate neural networks associated with respective representative sources of illumination; and

using training data of each neural network as a colorimetric value under a standard source of illumination.

69. The recording medium of claim 56, further comprising the steps of:

10 finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and

using training data of each neural network as a colorimetric value under a standard source of illumination.

15 70. A method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of:

determining, using a neural network, a correction to data representative of the color image based upon an estimated illuminant of the color image;

20 applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and

transmitting data representative of the corrected data.

25 71. The method of claim 70, wherein the electronic camera captures at least one still image.

72. The method of claim 70, wherein the electronic camera captures a succession of moving images.

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73. A method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of:

determining, using a multilayer perceptron model, a correction to data representative of the color image based upon an estimated illuminant of the color image;

applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and

transmitting data representative of the corrected data.

74. The method of claim 73, wherein the electronic camera captures at least one still image.

75. The method of claim 73, wherein the electronic camera captures a succession of moving images.

76. The method of claim 73, wherein the multilayer perceptron model is trained based upon a dogleg trust region implementation of a Levenberg-Marquardt type algorithm.

77. The method of claim 73, further comprising the step of: outputting an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

78. The method of claim 79, further comprising the step of: using training data of each neural network as a colorimetric value under a standard source of illumination.

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79. A method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of:

5 determining, using a coactive neuro-fuzzy inference system model, a correction to data representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and transmitting data representative of the corrected data.

10 80. The method of claim 79, wherein the electronic camera captures at least one still image.

81. The method of claim 79, wherein the electronic camera captures a succession of moving images.

15 82. The method of claim 79, wherein an integrating unit comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of color image capture.

20 83. The method of claim 82, further comprising the step of: constructing fuzzy membership functions by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

25 84. The method of claim 79, further comprising the step of: training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate

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transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

5 85. The method of claim 82, further comprising the step of:
 training the coactive neuro-fuzzy inference system
 model by constructing fuzzy membership functions generated
 by applying a neural network nonlinear coordinate
 transformation to a white balance plane in order to
10 characterize estimated illumination for the coactive neuro-
 fuzzy inference system model, wherein all parameters of fuzzy
 membership functions and local expert multilayer perceptrons
 are updated simultaneously.

15 86. The method of claim 82, further comprising the step of:
 training the coactive neuro-fuzzy inference system
 model by constructing fuzzy membership functions generated
 by applying a neural network nonlinear coordinate
 transformation to a white balance plane in order to
20 characterize estimated illumination for the coactive neuro-
 fuzzy inference system model, wherein all parameters of fuzzy
 membership functions and local expert multilayer perceptrons
 are updated simultaneously in conjunction with a heuristic
 parameter updating rule.

87. The method of claim 82, 83, 84, 85 or 86 wherein at least two of the fuzzy membership functions overlap.

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88. A method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of:

5 determining, using a coactive neuro-fuzzy inference system with a switching unit, a correction to data representative of the color image based upon an estimated illuminant of the color image; and
transmitting data representative of the corrected data.

89. The method of claim 79, further comprising the steps of:

10 finding a color conversion inverse map using separate neural networks associated with respective representative sources of illumination; and
outputting an output color space of the color corrected image as a space not normalized with chromaticity
15 coordinates the sources of illumination.

90. The method of claim 79, further comprising the steps of:

20 finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and
outputting an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

25 91. The method of claim 79, further comprising the steps of:

finding a color conversion inverse map using separate neural networks associated with respective representative sources of illumination; and

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using training data of each neural network as a colorimetric value under a standard source of illumination.

92. The method of claim 79, further comprising the steps of:

5 finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and

using training data of each neural network as a colorimetric value under a standard source of illumination.

10 93. The method of claim 1, 4 or 10, wherein the data representative of the color image includes information regarding the illuminant.

15 94. The apparatus of claim 24, 27 or 33, wherein the data representative of the color image includes information regarding the illuminant.

95. A method of recording image data obtained by an electronic camera, comprising the steps of:

capturing a color image and generating data representative of the image;

20 estimating an illuminant for the captured color image and generating data representative of the estimated illuminant; and

recording the data representative of the image with the data representative of the estimated illuminant.

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96. A method of transmitting image data obtained by an electronic camera, comprising the steps of:

capturing a color image and generating data representative of the image;

5 estimating an illuminant for the captured color image and generating data representative of the estimated illuminant; and

transmitting the data representative of the image with the data representative of the estimated illuminant.

AMENDED CLAIMS

[received by the International Bureau on 18 September 2000 (18.09.00);
original claim 20-23, 43-46, 66-69 and 89-92 amended;
remaining claims unchanged (23 pages)]

1. A method of correcting color of a color image obtained
by an electronic camera, comprising the steps of:

5 determining, using a neural network, a correction to
data representative of the color image based upon an
estimated illuminant of the color image; and

applying the correction to the data representative of the
color image, wherein the illuminant comprises multiple sources
of illumination.

10

2. The method of claim 1, wherein the electronic camera
captures at least one still image.

3. The method of claim 1, wherein the electronic camera
15 captures a succession of moving images.

4. A method of correcting color of a color image obtained
by an electronic camera, comprising the steps of:

20 determining, using a multilayer perceptron model, a
correction to data representative of the color image based
upon an estimated illuminant of the color image; and

applying the correction to the data representative of the
color image, wherein the illuminant comprises multiple sources
of illumination.

25

5. The method of claim 4, wherein the electronic camera
captures at least one still image.

6. The method of claim 4, wherein the electronic camera captures a succession of moving images.

7. The method of claim 4, wherein the multilayer
5 perceptron model is trained based upon a dogleg trust region implementation of a Levenberg-Marquardt type algorithm.

8. The method of claim 4, further comprising the step of:
outputting an output color space of the color corrected
10 image as a space not normalized with chromaticity coordinates the sources of illumination.

9. The method of claim 4, further comprising the step of:
using training data of each neural network as a
15 colorimetric value under a standard source of illumination.

10. A method of correcting color of a color image obtained by an electronic camera, comprising the steps of:
determining, using a coactive neuro-fuzzy inference
20 system model, a correction to data representative of the color image based upon an estimated illuminant of the color image;
and
applying the correction to the data representative of the
color image, wherein the illuminant comprises multiple sources
25 of illumination.

11. The method of claim 10, wherein the electronic camera captures at least one still image.

12. The method of claim 10, wherein the electronic camera captures a succession of moving images.

13. The method of claim 10, wherein an integrating unit
5 comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of color image capture.

14. The method of claim 13, further comprising the step of:
10 constructing fuzzy membership functions by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

15 15. The method of claim 10, further comprising the step of:
training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to
20 characterize estimated illumination for the coactive neuro-fuzzy inference system model.

16. The method of claim 13, further comprising the step of:
training the coactive neuro-fuzzy inference system
25 model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy

membership functions and local expert multilayer perceptrons are updated simultaneously.

5 17. The method of claim 13, further comprising the step of:
training the coactive neuro-fuzzy inference system
model by constructing fuzzy membership functions generated
by applying a neural network nonlinear coordinate
transformation to a white balance plane in order to
characterize estimated illumination for the coactive neuro-
10 fuzzy inference system model, wherein all parameters of fuzzy
membership functions and local expert multilayer perceptrons
are updated simultaneously in conjunction with a heuristic
parameter updating rule.

15 18. The method of claim 13, 14, 15, 16 or 17, wherein at
least two of the fuzzy membership functions overlap.

 19. A method of correcting color of a color image obtained
by an electronic camera, comprising the steps of:
20 determining, using a coactive neuro-fuzzy inference
system with a switching unit, a correction to data
representative of the color image based upon an estimated
illuminant of the color image.

25 20. The method of claim 10, further comprising the steps
of:
 finding a color conversion inverse map using a plurality
of neural networks associated with respective representative
sources of illumination;

using a respective subset of training data to independently train each neural network in a component-wise manner, wherein each of the neural networks is a local expert neural network; and

5 outputting an output color space of the color corrected image as a space with chromaticity coordinates of the sources of illumination.

21. The method of claim 10, further comprising the steps
10 of:

 finding a color conversion inverse map using a plurality of neural networks associated with respective representative sources of illumination;

 using an entire training data set to simultaneously train
15 all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks; and

 outputting an output color space of the color corrected image as a space with chromaticity coordinates of the sources of illumination.

20

22. The method of claim 10, further comprising the steps
of:

 finding a color conversion inverse map using neural
networks associated with respective representative sources of
25 illumination; and

 using a respective subset of training data to independently train each neural network in a component-wise manner, wherein each of the neural networks is a local expert neural network.

23. The method of claim 10, further comprising the steps of:

5 finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and

using an entire training data set to simultaneously train all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks.

10

24. An apparatus for correcting color of a color image obtained by an electronic camera, comprising:

15 a neural network for determining a correction to data representative of the color image based upon an estimated illuminant of the color image and for applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

25. The apparatus of claim 24, wherein the electronic camera captures at least one still image.

20

26. The apparatus of claim 24, wherein the electronic camera captures a succession of moving images.

27. An apparatus for correcting color of a color image obtained by an electronic camera, comprising:

25

a multilayer perceptron model for determining a correction to data representative of the color image based upon an estimated illuminant of the color image, and for

applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination.

5 28. The apparatus of claim 27, wherein the electronic camera captures at least one still image.

 29. The apparatus of claim 27, wherein the electronic camera captures a succession of moving images.

10 30. The apparatus of claim 27, wherein the multilayer perceptron model is trained based upon a dogleg trust region implementation of a Levenberg-Marquardt type algorithm.

15 31. The apparatus of claim 27, wherein the multilayer perceptron model outputs an output color space of the color corrected image as a space not normalized with chromaticity coordinates the sources of illumination.

20 32. The apparatus of claim 27, wherein the multilayer perceptron model uses training data of each neural network as a colorimetric value under a standard source of illumination.

 33. An apparatus for correcting color of a color image
25 obtained by an electronic camera, comprising:
 a coactive neuro-fuzzy inference system model for determining a correction to data representative of the color image based upon an estimated illuminant of the color image, and for applying the correction to the data representative of

the color image, wherein the illuminant comprises multiple sources of illumination.

34. The apparatus of claim 33, wherein the electronic
5 camera captures at least one still image.

35. The apparatus of claim 33, wherein the electronic camera captures a succession of moving images.

10 36. The apparatus of claim 33, wherein an integrating unit comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of color image capture.

15 37. The apparatus of claim 36, wherein fuzzy membership functions are constructed by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

20 38. The apparatus of claim 33, wherein the coactive neuro-fuzzy inference system model is trained by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order
25 to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

39. The apparatus of claim 36, wherein the coactive neuro-fuzzy inference system model is trained by constructing fuzzy

membership functions generated by applying a neural network
nonlinear coordinate transformation to a white balance plane in order
to characterize estimated illumination for the coactive neuro-fuzzy
inference system model, wherein all parameters of fuzzy membership
5 functions and local expert multilayer perceptrons are updated
simultaneously.

40. The apparatus of claim 36, wherein the coactive neuro-
fuzzy inference system model is trained by constructing fuzzy
10 membership functions generated by applying a neural network
nonlinear coordinate transformation to a white balance plane in order
to characterize estimated illumination for the coactive neuro-fuzzy
inference system model, wherein all parameters of fuzzy membership
functions and local expert multilayer perceptrons are updated
15 simultaneously in conjunction with a heuristic parameter updating
rule.

41. The apparatus of claim 36, 37, 38, 39 or 40, wherein
at least two of the fuzzy membership functions overlap.
20

42. An apparatus for correcting color of a color image
obtained by an electronic camera, comprising:
a coactive neuro-fuzzy inference system with a
switching unit for determining a correction to data
25 representative of the color image based upon an estimated
illuminant of the color image.

43. The apparatus of claim 33, wherein the coactive neuro-
fuzzy inference system model finds a color conversion inverse map

using a plurality of neural networks associated with respective representative sources of illumination, uses a respective subset of training data to independently train each neural network in a component-wise manner, wherein each of the neural networks is a local expert neural network, and outputs an output color space of the color corrected image as a space with chromaticity coordinates of the sources of illumination.

44. The apparatus of claim 33, wherein the coactive neuro-fuzzy inference system model finds a color conversion inverse map using a plurality of neural networks associated with respective representative sources of illumination, uses an entire training data set to simultaneously train all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks, and outputs an output color space of the color corrected image as a space with chromaticity coordinates of the sources of illumination.

45. The apparatus of claim 33, wherein the coactive neuro-fuzzy inference system model finds a color conversion inverse map using neural networks associated with respective representative sources of illumination, and uses a respective subset of training data to independently train each neural network in a component-wise manner, wherein each of the neural networks is a local expert neural network.

46. The apparatus of claim 33, wherein the coactive neuro-fuzzy inference system model finds a color conversion inverse map using neural networks associated with respective representative

sources of illumination, and uses an entire training data set to simultaneously train all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks.

5

47. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:

10

determining, using a neural network, a correction to data representative of the color image based upon an estimated illuminant of the color image;

applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and

15

recording on the recording medium data representative of the corrected data.

48. The recording medium 47, wherein the electronic camera captures at least one still image.

20

49. The recording medium of claim 47, wherein the electronic camera captures a succession of moving images.

25

50. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:

determining, using a multilayer perceptron model, a correction to data representative of the color image based upon an estimated illuminant of the color image;

applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and

5 recording on the recording medium data representative of the corrected data.

51. The recording medium of claim 50, wherein the electronic camera captures at least one still image.

10 52. The recording medium of claim 50, wherein the electronic camera captures a succession of moving images.

53. The recording medium of claim 50, wherein the multilayer perceptron model is trained based upon a dogleg trust region implementation of a Levenberg-Marquardt type algorithm.

54. The recording medium of claim 54, further comprising the step of:
outputting an output color space of the color corrected
20 image as a space not normalized with chromaticity coordinates the sources of illumination.

55. The recording medium of claim 50, further comprising the step of:
25 using training data of each neural network as a colorimetric value under a standard source of illumination.

56. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:

5 determining, using a coactive neuro-fuzzy inference system model, a correction to data representative of the color image based upon an estimated illuminant of the color image; applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and
10 recording on the recording medium data representative of the corrected data.

57. The recording medium of claim 56, wherein the electronic camera captures at least one still image.

15

58. The recording medium of claim 56, wherein the electronic camera captures a succession of moving images.

59. The recording medium of claim 56, wherein an
20 integrating unit comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of color image capture.

25 60. The recording medium of claim 59, further comprising the step of:
 constructing fuzzy membership functions by applying a neural network nonlinear coordinate transformation to a white

balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

61. The recording medium of claim 56, further comprising
5 the step of:

training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to
10 characterize estimated illumination for the coactive neuro-fuzzy inference system model.

62. The recording medium of claim 59, further comprising
the step of:

15 training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-
20 fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously.

63. The recording medium of claim 59, further comprising
25 the step of:

training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to

5 characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously in conjunction with a heuristic parameter updating rule.

64. The recording medium of claim 59, 60, 61, 62 or 63, wherein at least two of the fuzzy membership functions overlap.

10 65. A recording medium having recorded thereon color corrected data of a color image obtained by an electronic camera, the recording medium being prepared by the steps of:

15 determining, using a coactive neuro-fuzzy inference system with a switching unit, a correction to data representative of the color image based upon an estimated illuminant of the color image; and
recording on the recording medium data representative of the corrected data.

20 66. The recording medium of claim 56, further comprising the steps of:

25 finding a color conversion inverse map using a plurality of neural networks associated with respective representative sources of illumination;
using a respective subset of training data to independently train each neural network in a component-wise manner, wherein each of the neural networks is a local expert neural network; and
outputting an output color space of the color corrected

image as a space with chromaticity coordinates of the sources of illumination.

5 67. The recording medium of claim 56, further comprising the steps of:

 finding a color conversion inverse map using a plurality of neural networks associated with respective representative sources of illumination;

10 using an entire training data set to simultaneously train all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks; and

 outputting an output color space of the color corrected image as a space with chromaticity coordinates of the sources of illumination.

15

 68. The recording medium of claim 56, further comprising the steps of:

 finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and

20

 using a respective subset of training data to independently train each neural network in a component-wise manner, wherein each of the neural networks is a local expert neural network.

25

 69. The recording medium of claim 56, further comprising the steps of:

 finding a color conversion inverse map using neural networks associated with respective representative sources of

illumination; and

using an entire training data set to simultaneously train all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks.

5

70. A method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of:

10 determining, using a neural network, a correction to data representative of the color image based upon an estimated illuminant of the color image;

applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and

transmitting data representative of the corrected data.

15

71. The method of claim 70, wherein the electronic camera captures at least one still image.

20

72. The method of claim 70, wherein the electronic camera captures a succession of moving images.

25

73. A method of transmitting color corrected data of a color image obtained by an electronic camera, comprising the steps of:

determining, using a multilayer perceptron model, a correction to data representative of the color image based upon an estimated illuminant of the color image;

applying the correction to the data representative of the color image, wherein the illuminant comprises multiple sources of illumination; and

transmitting data representative of the corrected data.

74. The method of claim 73, wherein the electronic camera captures at least one still image.

5

75. The method of claim 73, wherein the electronic camera captures a succession of moving images.

76. The method of claim 73, wherein the multilayer
10 perceptron model is trained based upon a dogleg trust region
implementation of a Levenberg-Marquardt type algorithm.

77. The method of claim 73, further comprising the step of:
outputting an output color space of the color corrected
15 image as a space not normalized with chromaticity
coordinates the sources of illumination.

78. The method of claim 79, further comprising the step of:
using training data of each neural network as a
20 colorimetric value under a standard source of illumination.

79. A method of transmitting color corrected data of a color
image obtained by an electronic camera, comprising the steps of:
determining, using a coactive neuro-fuzzy inference
25 system model, a correction to data representative of the color
image based upon an estimated illuminant of the color image;
applying the correction to the data representative of the
color image, wherein the illuminant comprises multiple sources
of illumination; and

transmitting data representative of the corrected data.

80. The method of claim 79, wherein the electronic camera captures at least one still image.

5

81. The method of claim 79, wherein the electronic camera captures a succession of moving images.

10

82. The method of claim 79, wherein an integrating unit comprised of fuzzy membership functions computes a weighted sum of outputs of local expert multilayer perceptrons based upon an on-camera estimation of illumination at a time of color image capture.

15

83. The method of claim 82, further comprising the step of: constructing fuzzy membership functions by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

20

84. The method of claim 79, further comprising the step of: training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to characterize estimated illumination for the coactive neuro-fuzzy inference system model.

25

85. The method of claim 82, further comprising the step of:

training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to
5 characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously.

10 86. The method of claim 82, further comprising the step of:
training the coactive neuro-fuzzy inference system model by constructing fuzzy membership functions generated by applying a neural network nonlinear coordinate transformation to a white balance plane in order to
15 characterize estimated illumination for the coactive neuro-fuzzy inference system model, wherein all parameters of fuzzy membership functions and local expert multilayer perceptrons are updated simultaneously in conjunction with a heuristic parameter updating rule.

20 87. The method of claim 82, 83, 84, 85 or 86 wherein at least two of the fuzzy membership functions overlap.

88. A method of transmitting color corrected data of a color
25 image obtained by an electronic camera, comprising the steps of:
determining, using a coactive neuro-fuzzy inference system with a switching unit, a correction to data representative of the color image based upon an estimated illuminant of the color image; and

transmitting data representative of the corrected data.

89. The method of claim 79, further comprising the steps of:

5 finding a color conversion inverse map using a plurality of neural networks associated with respective representative sources of illumination;

using a respective subset of training data to independently train each neural network in a component-wise
10 manner, wherein each of the neural networks is a local expert neural network; and

outputting an output color space of the color corrected image as a space with chromaticity coordinates of the sources of illumination.

15

90. The method of claim 79, further comprising the steps of:

finding a color conversion inverse map using a plurality of neural networks associated with respective representative
20 sources of illumination;

using an entire training data set to simultaneously train all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks; and

outputting an output color space of the color corrected
25 image as a space with chromaticity coordinates of the sources of illumination.

91. The method of claim 79, further comprising the steps of:

finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and

5 using a respective subset of training data to independently train each neural network in a component-wise manner, wherein each of the neural networks is a local expert neural network.

10 92. The method of claim 79, further comprising the steps of:

finding a color conversion inverse map using neural networks associated with respective representative sources of illumination; and

15 using an entire training data set to simultaneously train all of the neural networks in a system-wise manner, wherein the neural networks are local expert neural networks.

20 93. The method of claim 1, 4 or 10, wherein the data representative of the color image includes information regarding the illuminant.

25 94. The apparatus of claim 24, 27 or 33, wherein the data representative of the color image includes information regarding the illuminant.

95. A method of recording image data obtained by an electronic camera, comprising the steps of:

capturing a color image and generating data representative of the image;

estimating an illuminant for the captured color image and
generating data representative of the estimated illuminant; and
recording the data representative of the image with the data
representative of the estimated illuminant.

5

96. A method of transmitting image data obtained by an
electronic camera, comprising the steps of:

capturing a color image and generating data representative of
the image;

10

estimating an illuminant for the captured color image and
generating data representative of the estimated illuminant; and
transmitting the data representative of the image with the
data representative of the estimated illuminant.

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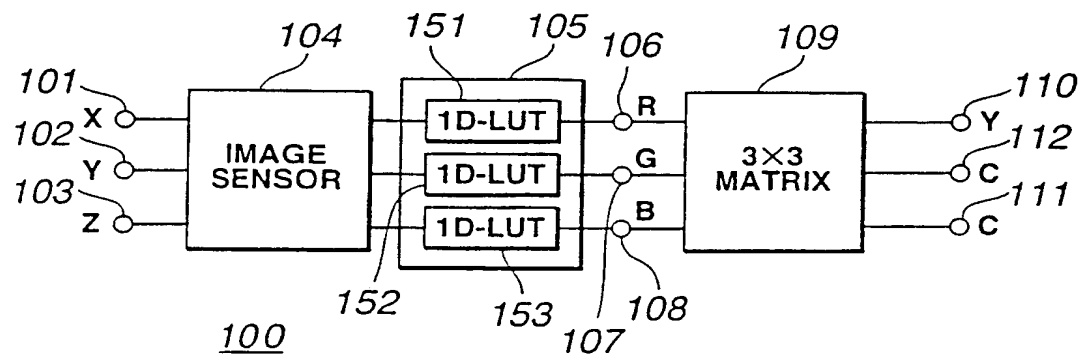


FIG. 1

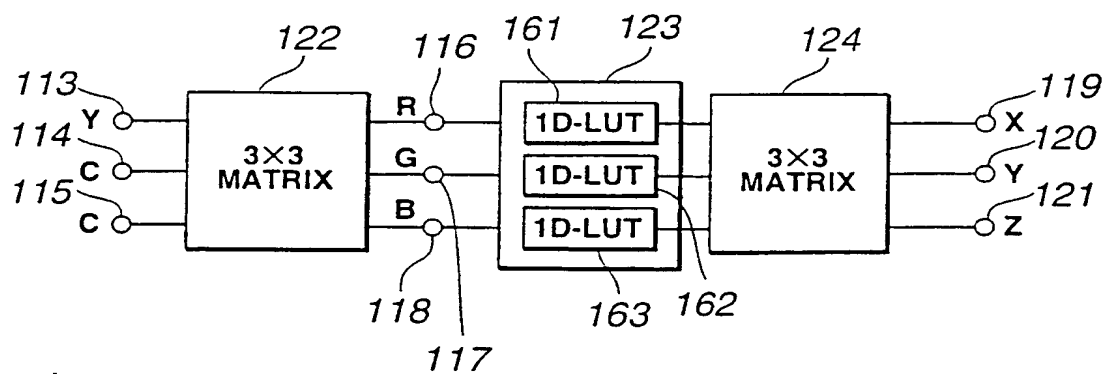


FIG. 2

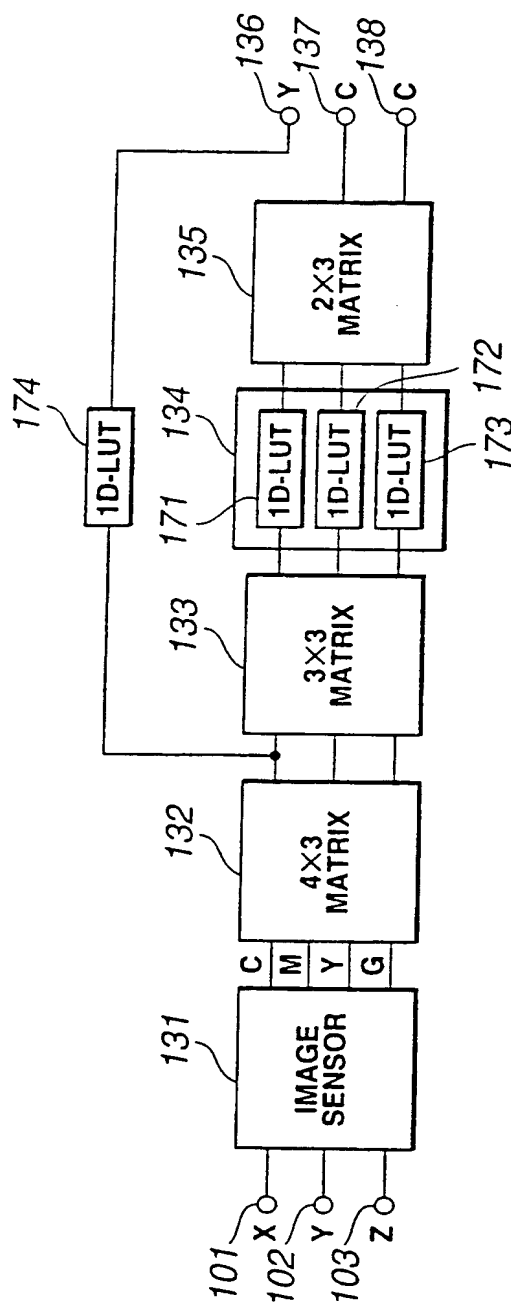
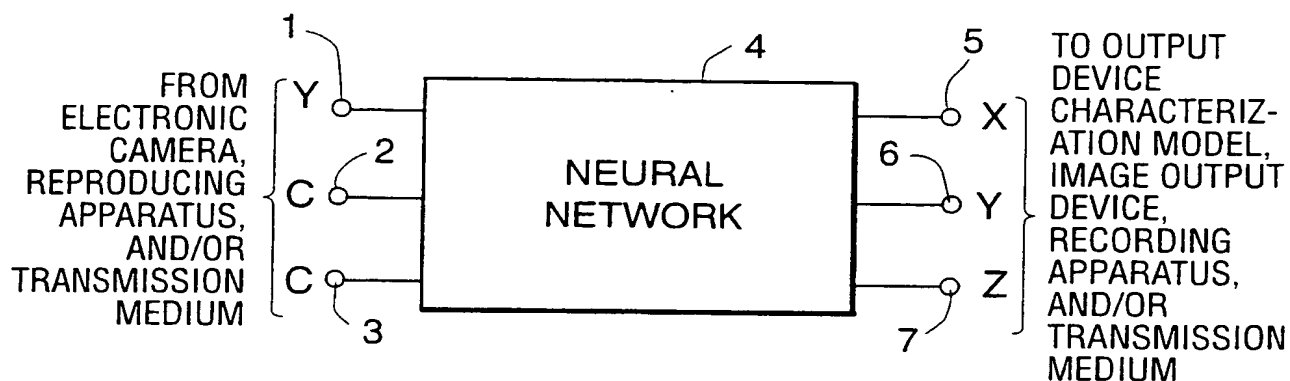
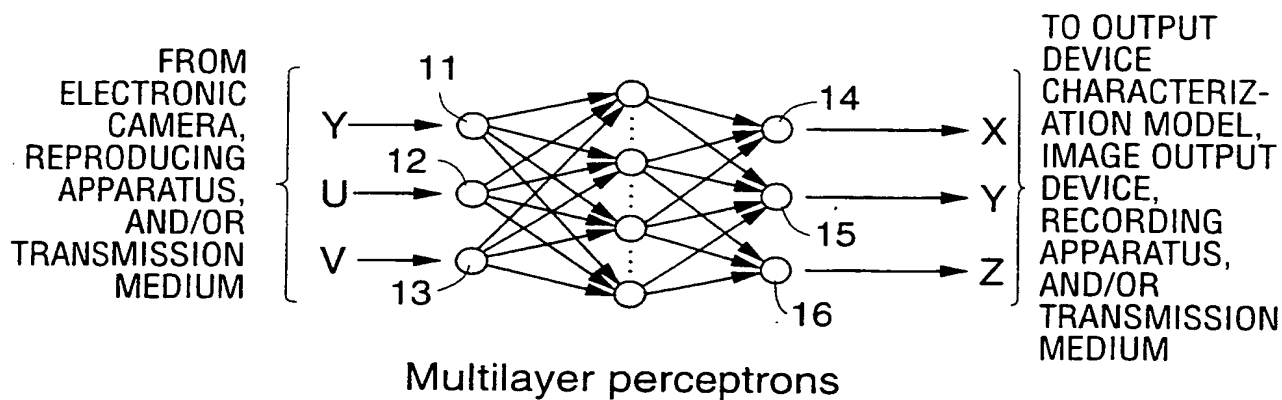


FIG. 3

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**FIG. 4A****FIG. 4B**

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White balance plane

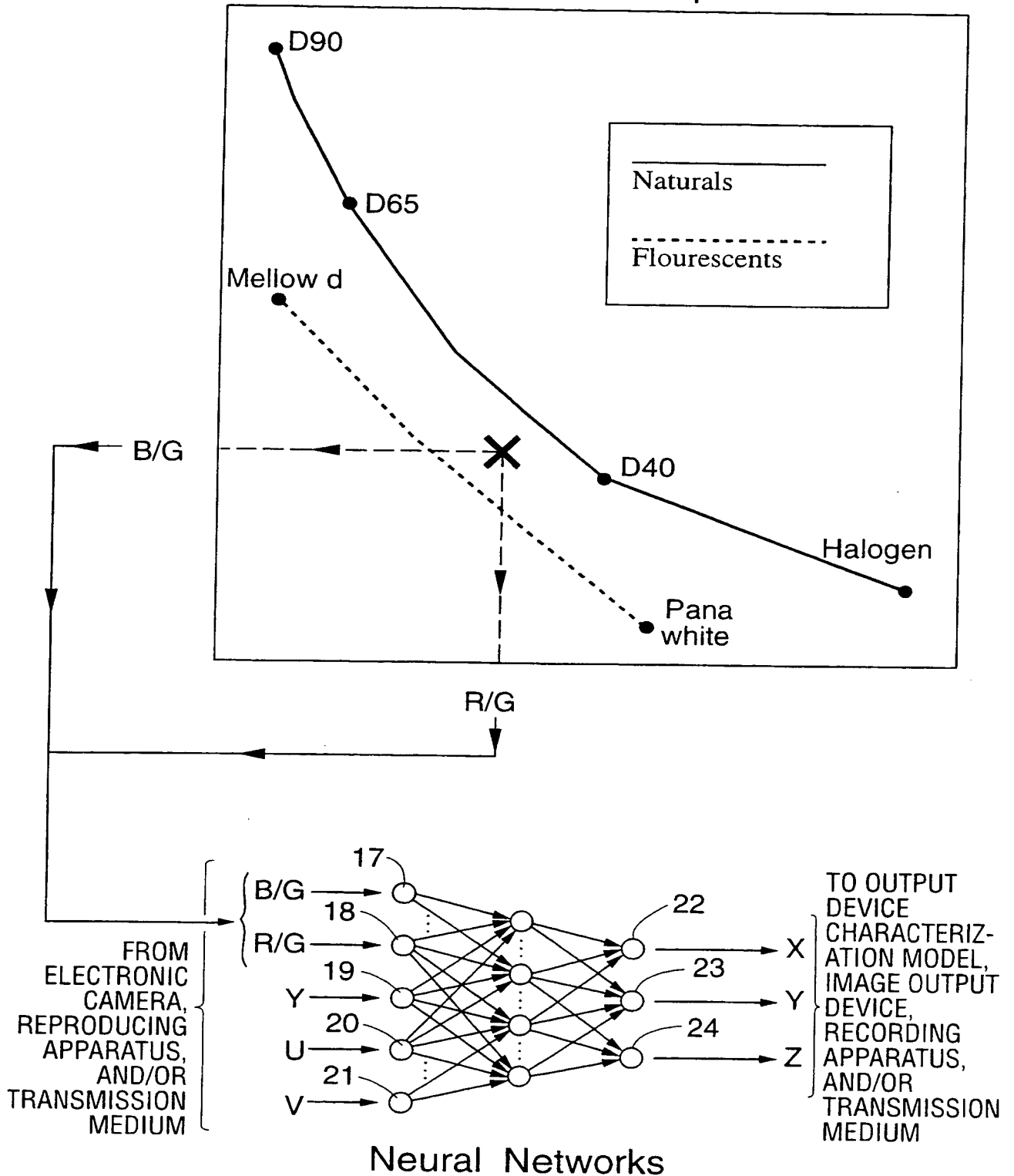
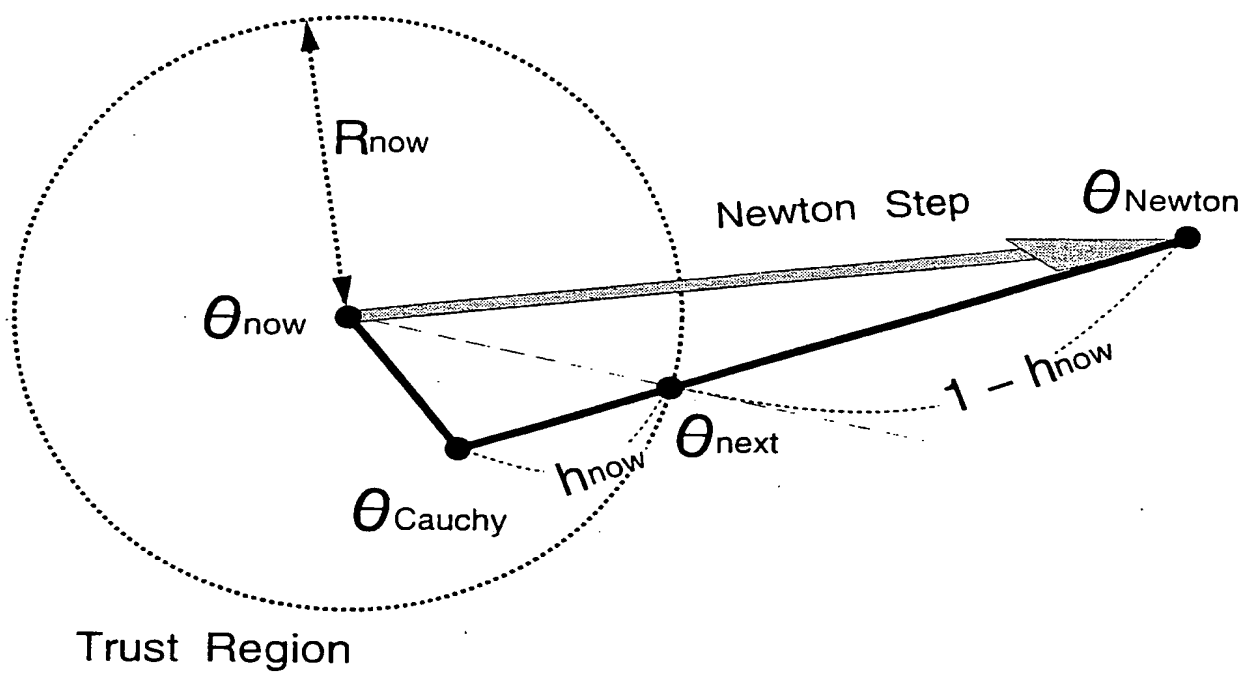
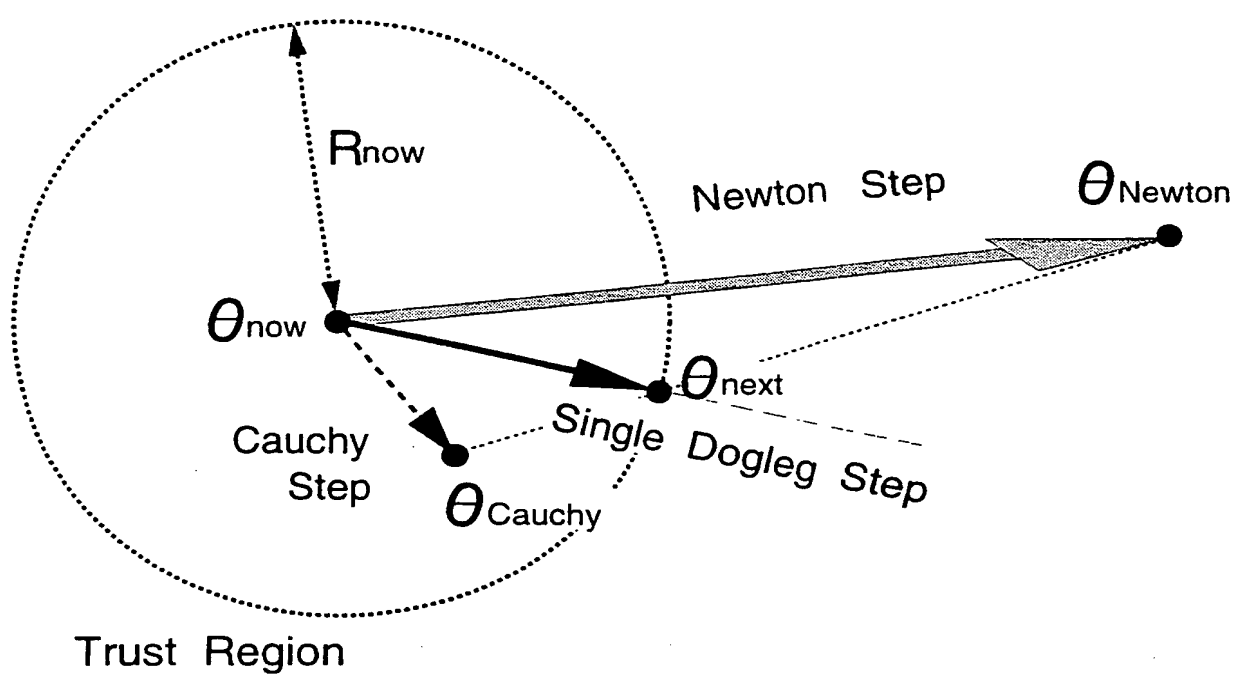


FIG. 5

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**FIG. 6A**

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**FIG. 6B**

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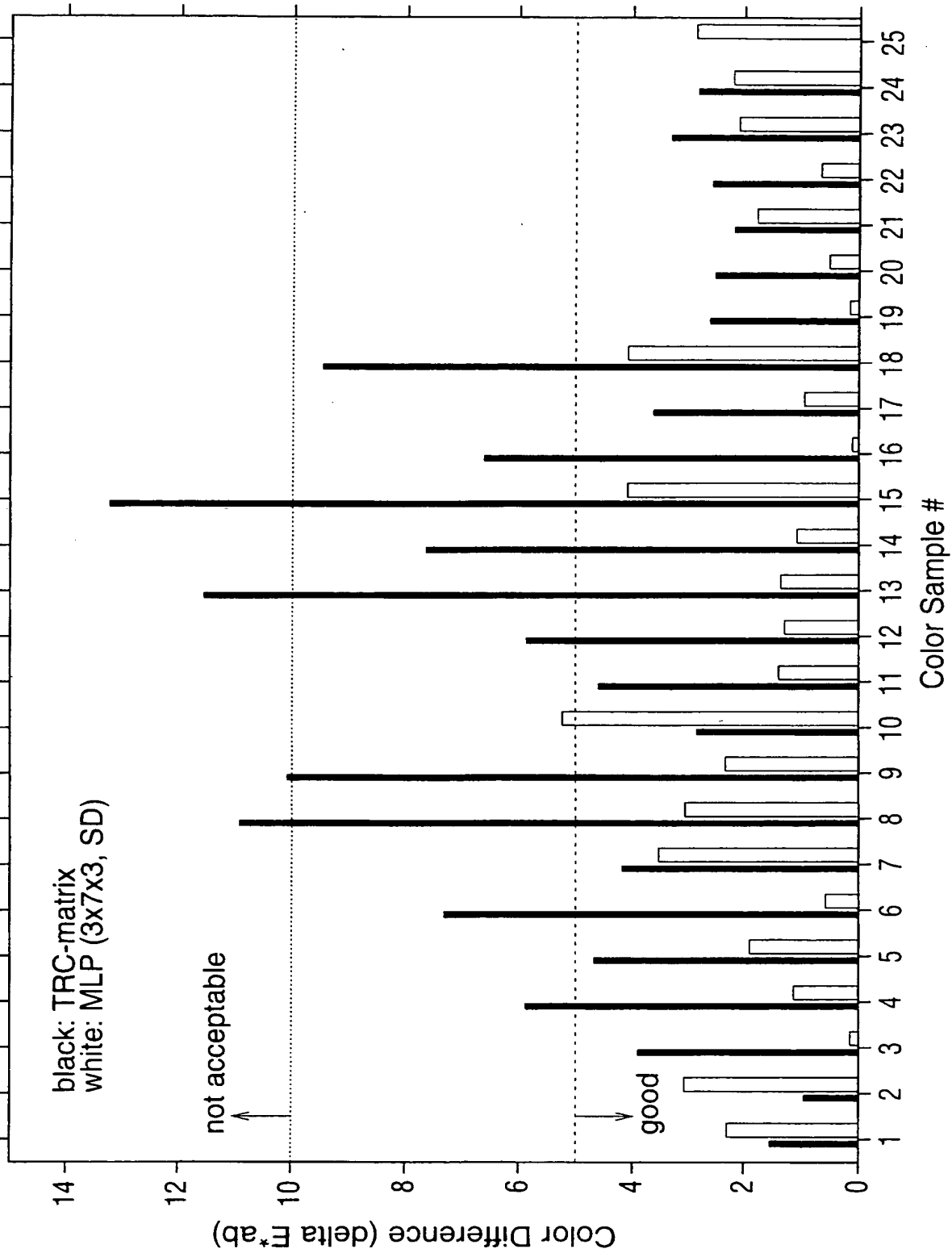
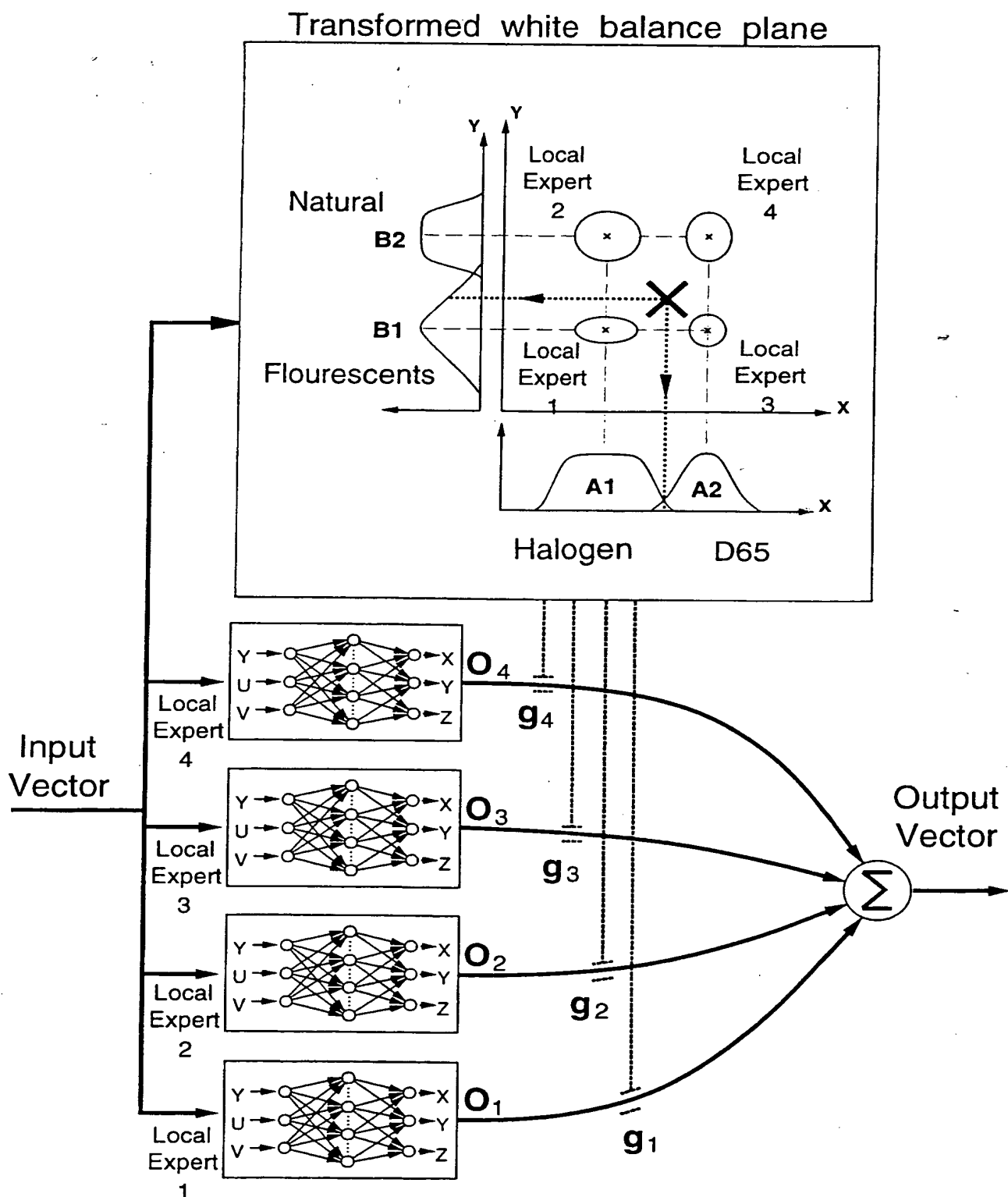


FIG. 7

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**FIG. 8**

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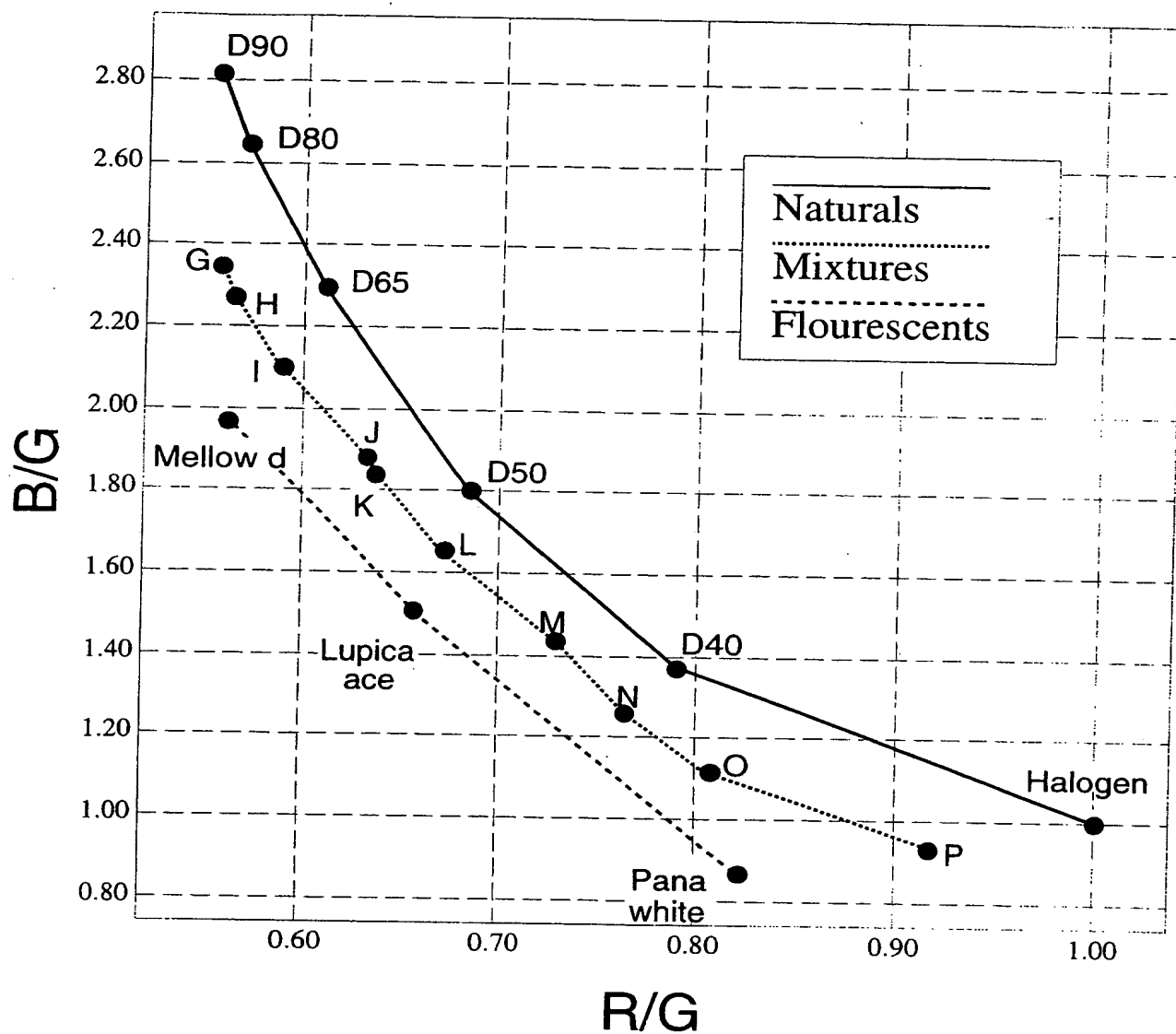
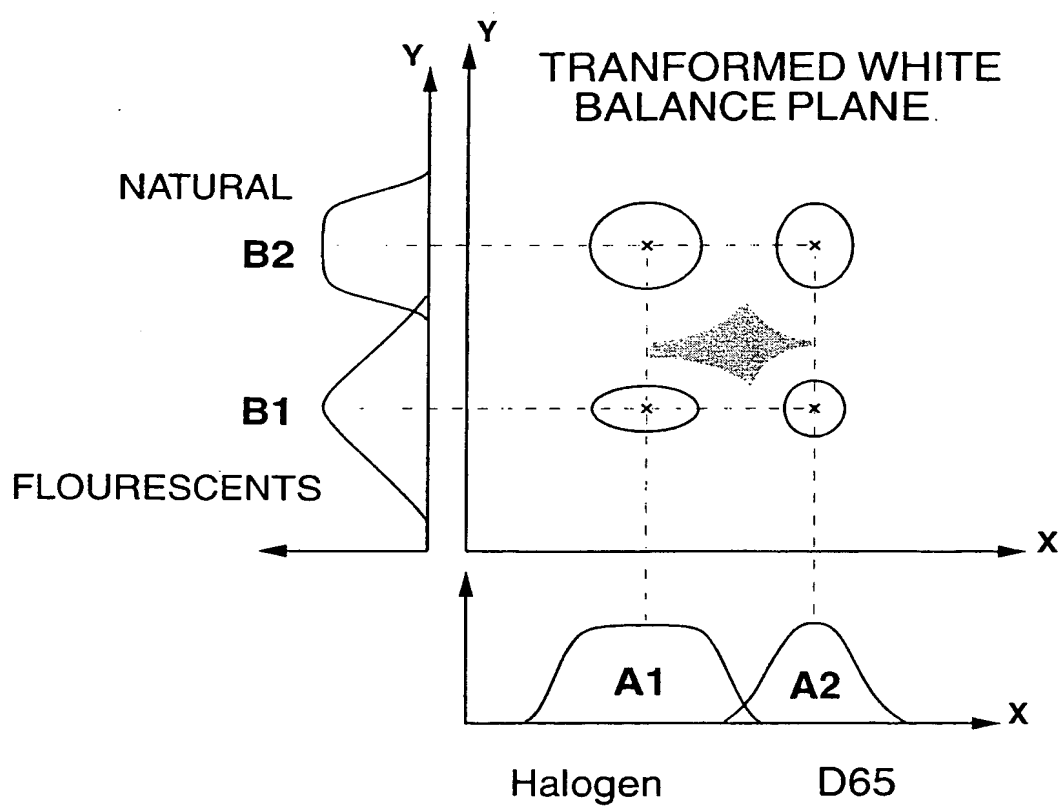
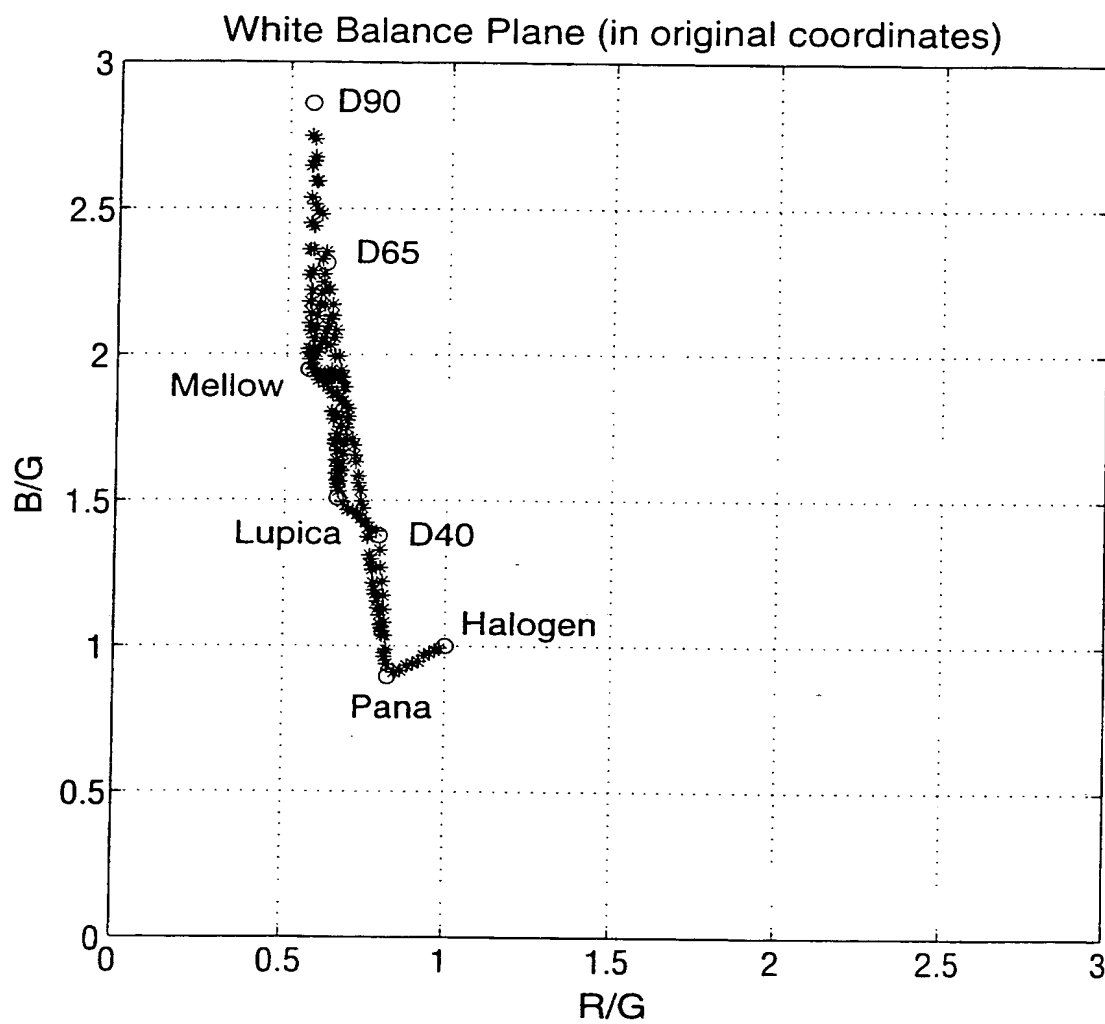


FIG. 9

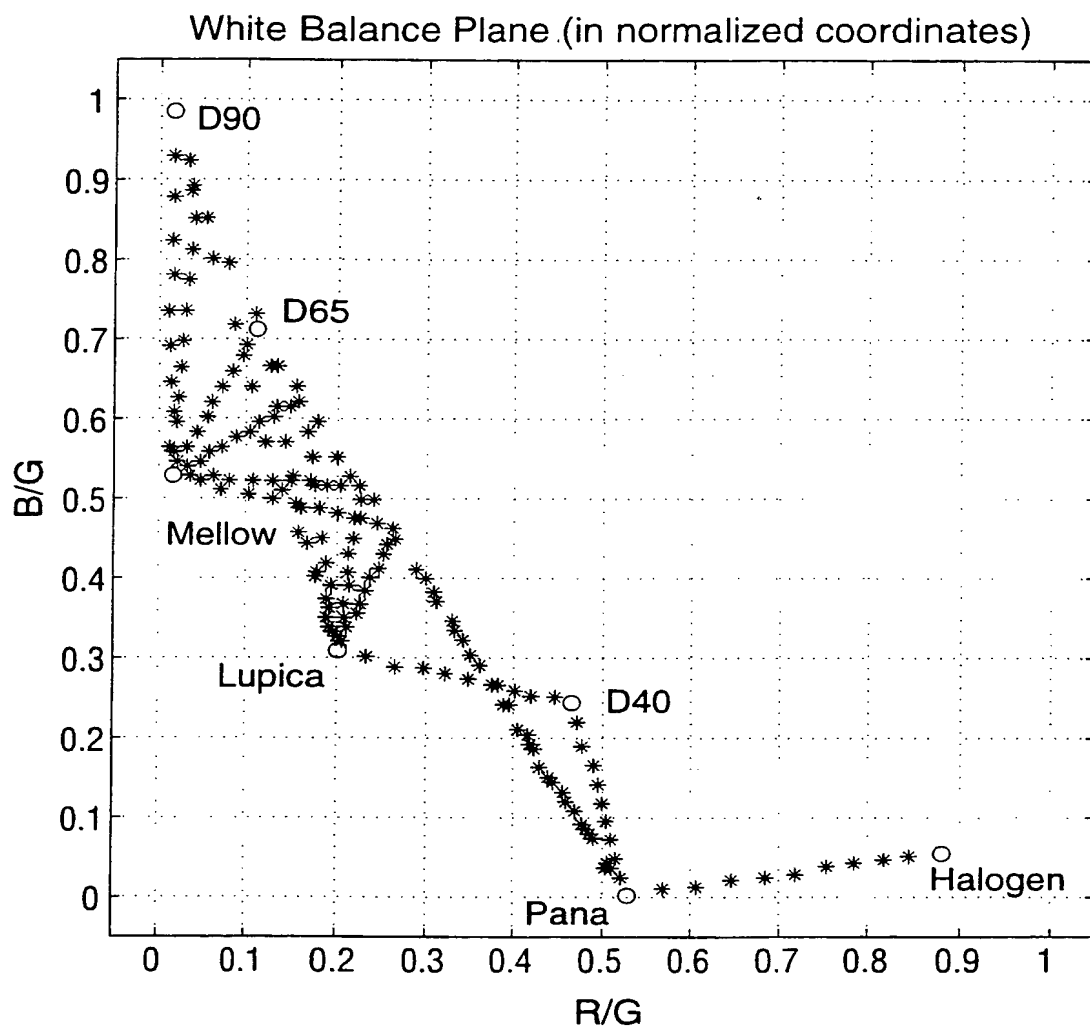
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**FIG. 10**

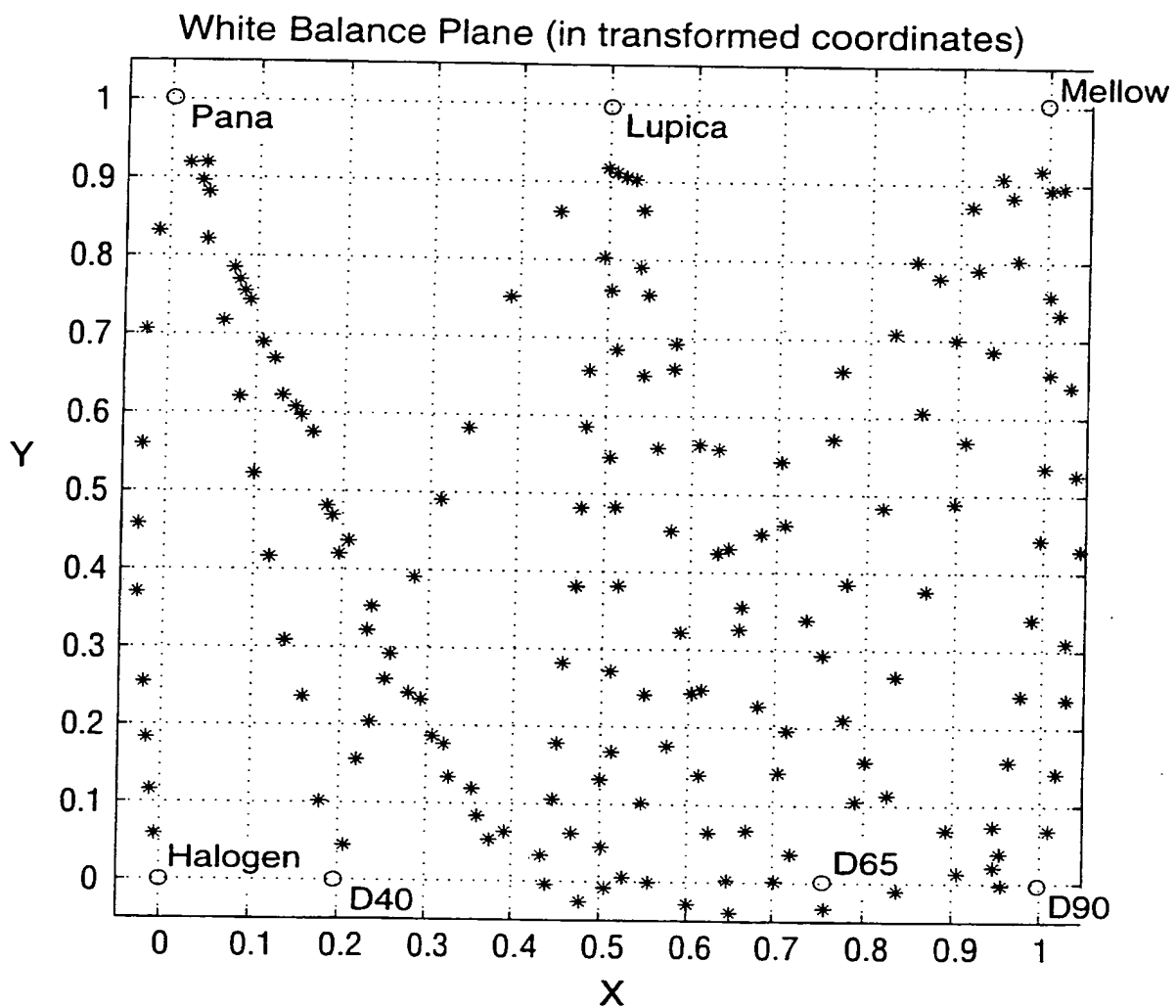
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**FIG. 11**

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**FIG. 12**

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**FIG. 13**

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/11504

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N9/64 H04N9/68

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, WPI Data, INSPEC, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>EP 0 720 390 A (MATSUSHITA ELECTRIC IND CO LTD) 3 July 1996 (1996-07-03)</p> <p>page 1, line 1 -page 2, line 19; figures 1,2</p> <p>page 4, line 1 - line 52; figures 3-48</p> <p>---</p> <p>-/--</p>	<p>1,4,10, 19,24, 27,33, 47,50, 65,70, 73,79, 88,95,96</p>

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

2 August 2000

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INTERNATIONAL SEARCH REPORT

International Application No

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>PATENT ABSTRACTS OF JAPAN vol. 016, no. 551 (P-1453), 20 November 1992 (1992-11-20) & JP 04 208928 A (OLYMPUS OPTICAL CO LTD), 30 July 1992 (1992-07-30)</p> <p>abstract</p> <p>---</p>	<p>1,2,4,5, 10,11, 19,24, 25,27, 28,33, 34,47, 48,50, 51,56, 57,65, 70,71, 73,74, 79,80, 88,95,96</p>
A	<p>US 5 376 963 A (ZORTEA ANTHONY E) 27 December 1994 (1994-12-27)</p> <p>the whole document</p> <p>-----</p>	<p>1,4,10, 19,24, 27,33, 47,50, 65,70, 73,79, 88,95,96</p>

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